B.R. 77

MACHINERY HANDBOOK

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Ronald Thompson.

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MACHINERY HANDBOOK

1. This handbook supersedes the Stokers Manual and is to be issued free of charge to each direct entry engine-room artificer, engine-room artificer apprentice and stoker on joining.

2. Ratings undergoing courses, who have not already received a copy of the Machinery Handbook, are to be issued with a copy free of charge.

3. Only one copy of this handbook will be issued free of charge to the above-mentioned ratings. Issues to replace copies lost are to be made on repayment.

4. In order that a copy of this handbook may be issued on temporary loan to men who are preparing to take an examination for advancement to a higher rating, a number of copies, equal to ten per cent. of the engine-room complement, will be supplied to each of H.M. Ships on demand.

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INTRODUCTION.

This handbook contains a brief description and method of operation of typical examples of the boilers and machinery in H.M. Ships for which the engine-room department is responsible. It is not possible in a book of this size to give detailed instructions for the operation of each of the many types of engines fitted. Instruction cards and books are provided by the engine makers, and ratings responsible for the operation and maintenance of machinery should make themselves familiar with these special instructions, in addition to the general instructions contained in this book.

On first going to sea, a junior engine-room rating will generally be employed in a boiler room, and his first step will be to prove himself an efficient and reliable boiler-room watchkeeper. During his period of training in the boiler rooms, an engine-room rating should acquire a thorough knowledge of the first seven chapters of this handbook.

As opportunity offers junior engine-room ratings who have qualified as boiler-room watchkeepers, and have shown that they are capable and zealous in the performance of their duties, will be selected for training as watchkeepers in the engine room. Particular attention should be paid during this period to Chapters VIII to XII.

Stokers who are selected by the Engineer Officer as likely to make good leading stokers will be given a course as watchkeepers on the auxiliary machinery described in Chapters XIII to XV, and will, if they show themselves worthy, be recommended for the Leading Stokers Course at the Mechanical Training Establishment at their home port. Attention to the instruction given at this course will enable a leading stoker or stoker to acquire the professional knowledge necessary for advancement to stoker petty officer, if recommended in due course. A limited number of those leading stokers and stokers who display particular ability during the Leading Stokers Course will be selected for a further course at the end of which they will, if they possess the necessary ability and are successful in the examination, be rated mechanician.

Advancement is open by examination and selection for stoker petty officers to chief stoker, and for engine-room artificers and mechanicians to chief engine-room artificer or chief mechanician and also to warrant and commissioned officer.

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CHAPTER I.

GENERAL.

1. Propelling Machinery.—The engines used for the propulsion of a ship are known as the main engines, and may be one of three types :—

(i) *Steam reciprocating engine*, in which steam, raised under pressure by the combustion of fuel in a boiler or boilers, is used to cause pistons to reciprocate to and fro in cylinders. By means of cranks the reciprocating motion of the pistons is used to rotate a shaft and thus drive a screw propeller.

(ii) *Steam turbine*, in which the steam from boilers passing through a series of vanes or blades, causes the wheels to which the blades are attached to rotate. This rotary motion can be transferred direct to the shaft carrying the propeller, but in modern ships the turbines drive the propeller shaft through reduction gearing and thus the propeller rotates at a lower speed than the turbines.

(iii) *Internal-combustion engine*, in which the fuel is burnt in the cylinders of a reciprocating engine. Both gaseous and liquid fuels are used in internal-combustion engines, but only those using the less volatile liquid fuels are suitable for the propulsion of ships. Such engines are known as oil engines or diesel engines. Petrol engines are commonly used for ships' boats.

Of these three types the steam reciprocating engine was the only one available up to the end of the last century. The steam was produced in coal-fired boilers. These were generally of the cylindrical type, but the water-tube boiler was then being adopted for warships.

The steam turbine was first used for the propulsion of ships at the beginning of the present century, and by this time the development of the petroleum industry had made available oil fuels for use in boilers and in internal-combustion engines. By the use of turbines and oil-fired water-tube boilers a considerable reduction in the weight of the propelling machinery was possible, or alternatively machinery of higher power could be fitted and a higher speed obtained. In the case of warships a high speed is particularly desirable, and also any saving in the weight of machinery allows of a corresponding increase in the weight of guns and armour. The adoption of the steam turbine and oil-fired water-tube boilers was therefore more rapid in the case of warships than in the case

of merchant ships. At the present time the only ships in H.M. Navy propelled by steam-reciprocating engines are some of the smaller vessels, for which a high speed is not required. The marine oil engine was introduced for ship's propulsion at about the same time as the steam turbine, and on account of its economy in fuel consumption has been extensively adopted for merchant ships. The weight of the oil engine has, however, prevented the general adoption of this type of machinery for warships. In the case of submarines, being able to dispense with boilers is a great advantage, and oil engines are now used in all these vessels.

2. Auxiliary Machinery.—In addition to the main engines, all ships require a certain number of auxiliary engines for various purposes. In some small ships with steam reciprocating engines, some of these auxiliaries may be driven from the main engines, but it is more usual to provide a separate small steam engine, or in some cases an electric motor, to operate each auxiliary.

The following is a list of the auxiliary machinery generally fitted in turbine-driven warships:—

Feed pumps for supplying water to the boilers.

Forced-draught fans for supplying the air for the combustion of the fuel in the boilers.

Oil-fuel pumps for supplying the fuel to the sprayers in ships with oil-fired boilers. These pumps are also used for transferring oil fuel from one tank to another in ships where special oil-fuel transfer pumps are not fitted.

Main circulating pumps for circulating sea water through the main condensers, in which the exhaust steam from the engines is condensed. These pumps also supply cooling water for lubricating oil and drain coolers. They can be used to pump water from the engine-room bilges, if the engine room is flooding due to damage to the ship.

Air pumps, or extraction pumps and air ejectors, for removing the condensate and air from the condensers.

Forced lubrication pumps for supplying oil to the bearings of the main engines.

Water service pumps are fitted in some ships for circulating sea water through coolers, when the main circulating pumps are not running. In other ships the fire and bilge are used for this.

Feed-water transfer pumps or overflow tank pumps for pumping boiler feed water from one tank to another.

Feed-heater drain pumps are fitted in some ships for pumping drain water for feed water heaters back into feed system.

Steering engines or motors for working the rudder for steering the ship.

Capstan engine for working the anchors and cables. In addition to the forward capstan the larger ships have another capstan aft for handling mooring wires, etc. The after capstan is always electrically driven.

Fire and bilge pumps for supplying the water to the fire service mains and for pumping out water from the bilges. Electrically driven pumps outside the machinery spaces are called hull and fire pumps.

Salvage pumps for pumping overboard large quantities of water in the case of damage to the ship. Steam ejectors may be fitted in some compartments for this purpose.

Electric generators for supplying electricity for lights and for electric motors.

Evaporating plant for making fresh water for washing and drinking, and for feed water for boilers.

Refrigerating plant for cooling the cold rooms for the stowage of meat and vegetables and for the making of ice.

Magazine-cooling plant for cooling the magazines; this is not fitted in the smaller ships.

Ventilating fans for the ventilating machinery compartments, etc. Supply fans are those which pump fresh air into a compartment, while those that remove foul and hot air are called exhaust fans.

Air compressors for compressing air for use in torpedoes and for the air blast of guns.

Hydraulic pumps for supplying water under pressure for operating the hydraulic machinery in the gun turrets of battleships.

3. Superheated Steam.—The temperature at which water boils when it is heated in a vessel depends on the pressure in the vessel. Fresh water when heated in an open vessel will boil at 212° F., and the continued application of heat will not increase the temperature as long as the steam formed be allowed a free escape to the atmosphere. If, however, the escape of the steam formed be stopped or restricted, so that the pressure in the vessel rises, the temperature of the boiling water will rise. The temperature of the steam leaving the boiling water will always be at the same temperature as the water, and such steam is known as saturated steam. If a vessel containing saturated steam be cooled some of the steam will condense and particles of water will be found in

the steam ; the temperature of the steam will not drop as long as the pressure remains constant.

If, however, a vessel containing saturated steam be heated and if there is no water present in the vessel, the temperature of the steam will rise and the steam will become superheated.

By the use of superheated steam in turbines a higher efficiency is obtained, *e.g.*, by raising the temperature of steam formed at 300 lb. per square inch from 419° F. to 700° F. before admitting it to the turbines, a saving in fuel consumption of about 15 per cent. is achieved. For reciprocating engines the use of saturated steam has the advantage that some of the steam condenses on the cylinder walls and the water formed acts as a lubricant for the piston. Superheated steam is now almost invariably used for both main and auxiliary turbines, but it is not used for reciprocating engines in H.M. ships.

In the boilers fitted in modern turbine-driven vessels, the steam, after leaving the generating portion of the boiler, passes through tubes fitted in such a position that they are exposed to the high temperature of the furnace gases. Saturated steam may be obtained for any reciprocating auxiliary engines fitted by tapping off some of the steam before it goes to the superheater.

CHAPTER II.

BOILERS AND BOILER FEED WATER.

4. Boilers.—There are two main types of boilers in general use.

(1) *Tank boilers*, those in which the water is heated in a cylindrical vessel by the combustion of the fuel in one or more smaller cylinders, known as furnaces, built inside the large cylindrical shell. There are a number of boilers of this type, but the only one used for marine engines is the *return tube cylindrical boiler*, which is sometimes called the Scotch boiler.

Vertical boilers are used to supply steam to small engines on shore, and are also fitted in destroyers to supply low-pressure steam for the ship's heating system.

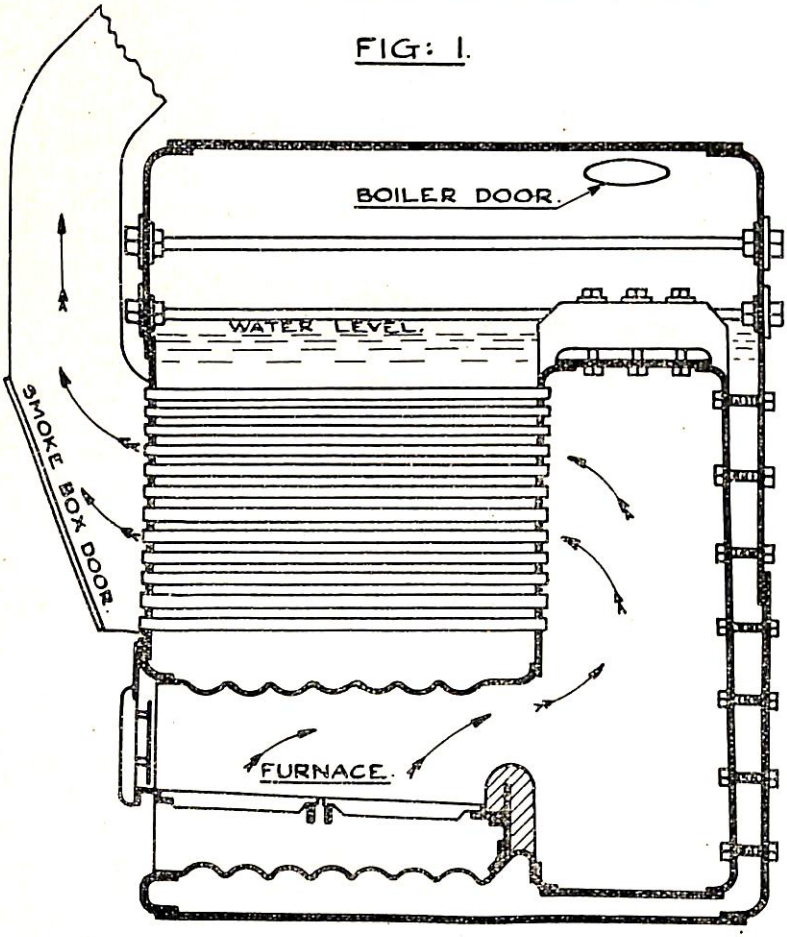
(2) *Water-tube boilers*, in which the water is heated in a large number of small steel tubes, arranged so that the products of the combustion of the fuel pass around the outside of the tubes. A number of different makes of water-tube boilers have been used in H.M. ships. Prior to the adoption of superheated steam the boilers most commonly fitted were the Yarrow three-drum boiler in all classes of ships, and the Babcock & Wilcox boiler in capital ships only. With the introduction of superheated steam the Admiralty superheater boiler was brought out to meet the special requirements of H.M. ships. This boiler will be found in the majority of H.M. ships now in service.

5. Comparison of Water Tube and Cylindrical Boiler.—For warships the water-tube boiler has many advantages over the cylindrical boiler. It is lighter, more suitable for burning oil fuel, and steam can be raised quicker. Also a water-tube boiler can be arranged to withstand higher pressures and give a higher degree of superheat. Cylindrical boilers are now only fitted in ships where only a low power is required and reciprocating engines are used. They will be found in H.M. Service in trawlers, boom defence vessels and other small ships, and also in shore establishments. When lighting up from cold, cylindrical boilers must be warmed up very slowly, as otherwise unequal expansion will cause some of the joints to leak; twelve hours or more is allowed for raising steam in a large cylindrical boiler. With water-tube boilers steam can be raised in two hours, or even less in emergency. More care is required in the operation of water-tube boilers on account of the much smaller quantity of water they contain, and distilled water

only must be used as feed. For cylindrical boilers shore water is commonly used and sea water may be used in emergency.

6. Return Tube Cylindrical Boiler.—Figure 1 shows a longitudinal section through a cylindrical boiler. The boiler consists of cylindrical shell formed of steel plates riveted together. Each end of the cylinder is closed by a flat circular end plate, flanged over to fit inside the cylindrical shell, and secured by rivets. Holes

FIG: 1.



CYLINDRICAL RETURN TUBE BOILER.

are cut in the lower portion of the front end plate to receive the furnaces. These are large corrugated steel tubes, riveted at one end to the front end plate. The back end of each furnace is open to a separate steel plate box known as a combustion chamber.

There may be from one to four furnaces and combustion chambers, depending on the size of the boiler.

A number of steel tubes, called smoke tubes, connect the upper part of each combustion chamber and the smoke box at the front of the boiler. The ends of these tubes fit into holes in the front of the combustion chamber and the front end plate, and are expanded to make watertight joints with these plates. All flat surfaces subjected to pressure have to be stayed to prevent distortion. A certain number of the tube holes are tapped and special tubes with a screw thread at each end, known as stay tubes, are fitted in these holes. Solid steel screwed stays are fitted to the backs and sides of the combustion chambers, and dog and bridge stays are fitted to support the top. The end plates, above the level of the top of the combustion chambers and between the furnaces, are supported by longitudinal stays.

The height of water in the boiler is kept above the top of the combustion chambers. The boiler shown is fitted to burn coal, which is shovelled through a door in the mouth of each furnace onto a grate consisting of two rows of firebars. Air is admitted to the space below the firebars in each furnace through a draught plate. Some cylindrical boilers are fitted to burn oil fuel, and in this case a grate is not fitted. The oil is sprayed into the furnace, and the air required for combustion is admitted with the spray.

The hot gases from the furnaces pass up the combustion chambers, through the tubes to the smoke box, and then through the uptake to the funnel.

The walls of the furnaces, combustion chambers and tubes form the heating surfaces, through which heat is conducted to the water in the boiler. These surfaces must be kept clean, both on the gas and water side. Doors are fitted on the front of the smoke box to allow of brushes being passed through the tubes to remove the soot. To give access to the water side of the heating surfaces a manhole door is provided on top of the shell, and one or more manholes are fitted on the front end plate.

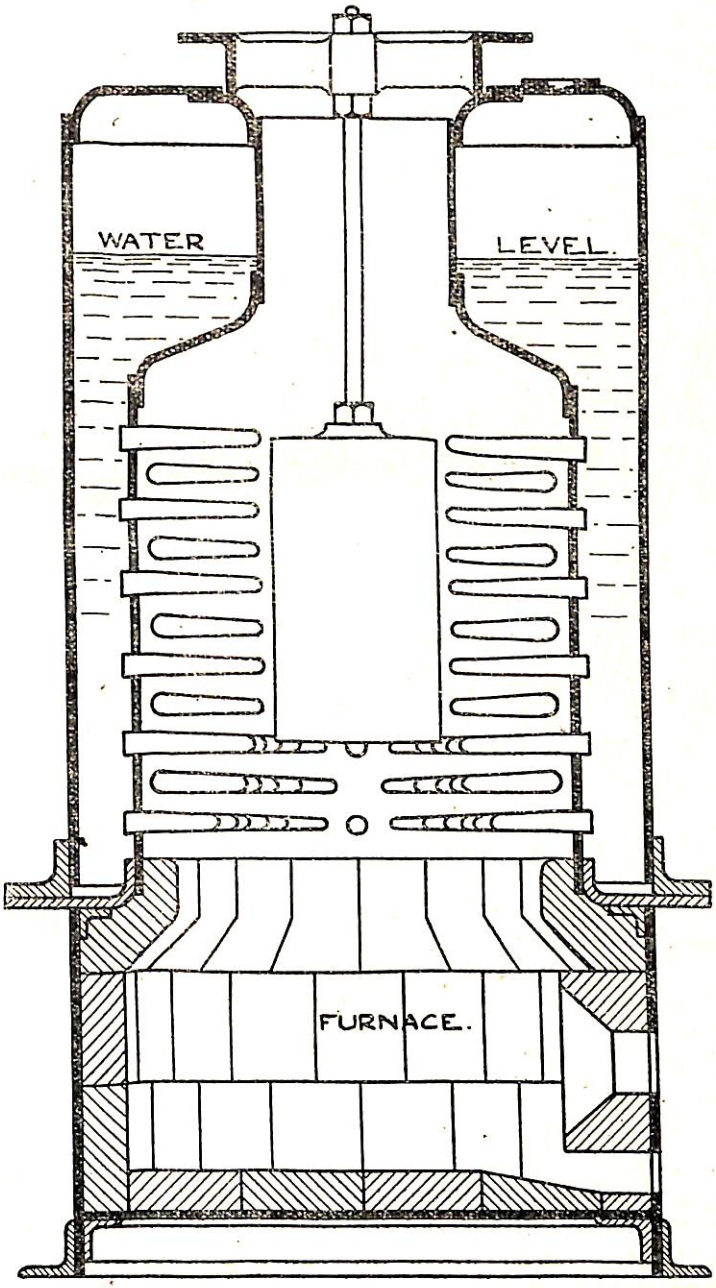
Superheaters are fitted to some cylindrical boilers. A " U "-shaped superheater tube is fitted in each smoke tube, the open ends of these tubes being bolted to headers in the smoke box. By passing the saturated steam from the boiler through these tubes a small degree of superheat is obtained. Cylindrical boilers are generally used in conjunction with reciprocating engines, and as superheated steam should not be admitted to these engines until they are thoroughly warm, arrangements are made to use saturated steam for warming the engines, and while getting underway.

7. Vertical Boilers.—For these boilers the bulk of the water is

contained in the annular space between two vertical cylinders of different diameter. The inner cylinder forms the combustion chamber, the furnace being situated at the bottom. From the top of the combustion chamber the gas passes through a vertical chimney tube, connecting the top of the inner cylinder to the top of the outer cylinder. Two methods are adopted to provide a larger heating surface in these boilers. In *cross tube vertical boilers* two large tubes are fitted across the top of the combustion chamber. The ends of the tubes are open to the water in the space between the two cylinders. In *thimble tube vertical boilers* a large number of short lengths of tube, sealed at one end and open at the other, project from the walls of the inner cylinder into the combustion space. Thimble tube boilers were introduced by a man named Clarkson, for raising steam from the heat in the exhaust gases of large oil engines, and they are often referred to as Clarkson boilers. Fig. 2 shows a section through one of these boilers, fitted in a destroyer for supplying low-pressure steam for the ship's heating system. The open end of each thimble tube is expanded into a hole in the inner cylinder. A cylindrical baffle or core, suspended in the centre of the combustion chamber, causes the hot gases to flow around the outside of the thimble tubes, and so impart heat to the water in the tubes. Breaking a joint at the top and bottom and raising the outer cylinder, gives access to the inside of the thimble tubes for cleaning purposes.

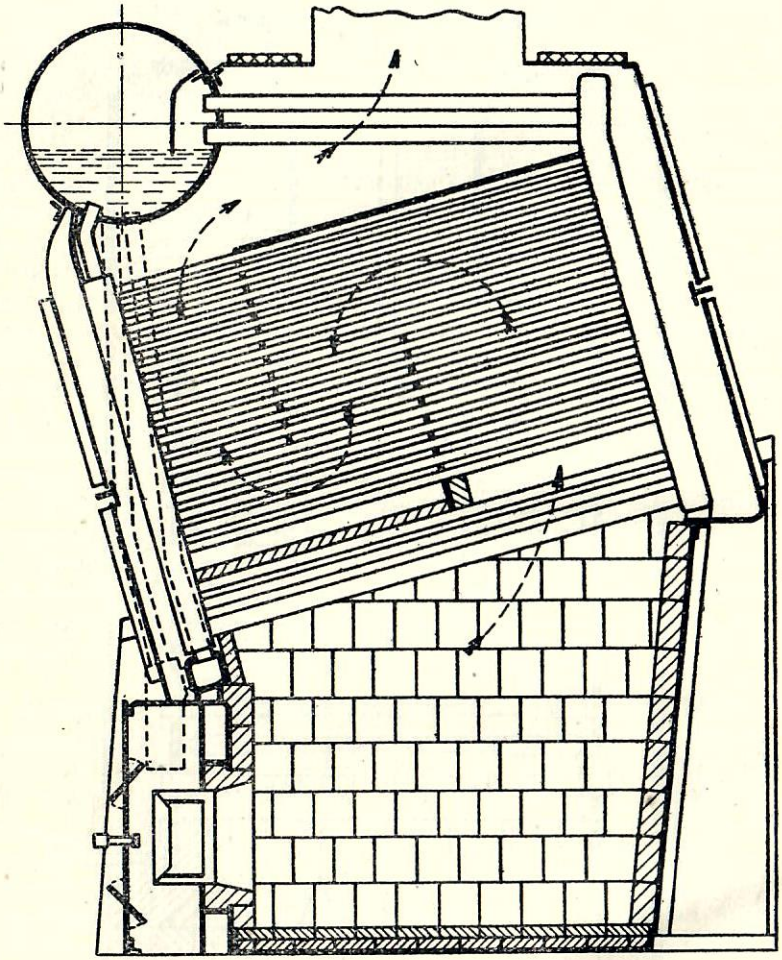
8. Babcock and Wilcox Boiler.—In this water-tube boiler the generator tubes, in which the water is heated, connect two rows of square section headers, one row down the front of the boiler and the other row down the back. The headers are displaced about 15 deg. from the vertical, as shown in Fig. 3, so that the generator tubes, which are at right angles to the headers, slope up from the front of the boiler to the back. Each front header is connected by a short length of tube to the bottom of a large cylindrical drum, known as the steam drum, situated across the front of the boiler. Each back header is also connected to the steam drum through two horizontal tubes, called return tubes. Feed water is admitted to the steam drum, the quantity admitted being controlled to keep a level of water in this drum up to the bottom row of return tubes. The formation of steam in the generator tubes causes a circulation of water, down the front headers, up the generator tubes and back headers, and thence back to the steam drum. An alternative path is provided for the flow of water to the bottom rows of generator tubes, which, being nearest the furnace, receive the greatest quantity of heat; the bottom of each front header is connected to a long square-section tube, known as the main mud drum, fitted across the front of the

FIG: 2



THIMBLE TUBE VERTICAL BOILER.

FIG: 3.



BABCOCK & WILCOX BOILER.

boiler. At each end of the main mud drum is a rectangular chamber, called an auxiliary mud drum, and two vertical tubes on each side of the boiler connect the bottom of the steam drum to the mud drums. These tubes, which are called downcomers, provide a supply of feed water to the bottom of the front headers. Any sediment which collects in the auxiliary mud drums can be blown out to the sea. Baffles are fitted to cause the hot gases from the

furnaces to flow in an S path across the outside of the generator tubes, and thence pass the return tubes to the uptake and funnel. All joints under pressure are made by expanding or swelling the ends of the tubes into holes cut in the headers and drums, hand-holes with doors being fitted where necessary to allow of the use of a roller-tube expander. By the removal of these handhole doors the inside of the tubes can be examined and cleaned. A manhole door is fitted to give access to the inside of the steam drum.

9. Three-Drum Boilers.—A number of water-tube boilers have been patented with different arrangements of tubes between three drums. The original arrangement of the tubes are in general no longer adhered to, and the patents have now expired. The *Yarrow boiler*, which in its original form had straight tubes, was the make most commonly fitted in H.M. ships. Three-drum boilers are often referred to as Yarrow-type boilers although they may not have any of the particular features of the original Yarrow boiler.

In these boilers a large number of steel tubes are arranged in the form of an inverted V to connect a large horizontal upper drum, known as the steam drum, and two smaller horizontal lower drums, known as water drums. The space between the tubes is enclosed by light steel casings, lined with asbestos, millboard and firebricks, to form a furnace in which the fuel is burnt. The front and back casings are continued on each side to enclose the tubes and join the side casings, which are at a sufficient distance from the outer rows of tubes to allow space for the furnace gases to pass to the uptakes and furnace. The products of combustion are thus confined to pass between the tubes, and in doing so impart heat to the water in the tubes.

The ends of the generator tubes pass through holes in the drums and project about $\frac{1}{4}$ of an inch inside. These projecting portions are belled out to prevent the tubes withdrawing, and each end of each tube is expanded to form a watertight joint in the hole of the drum. The cylindrical portions of the drums are sometimes solid-drawn, that is, rolled from a solid steel ingot without a joint. More usually drums consist of two semi-circular plates joined together, either by welding or by two longitudinal riveted joints, to form a hollow cylinder. The portion of each drum containing the holes for the tubes, known as the tube plate, is made thicker than the other portion, which is known as the wrapper plate. The ends of the drums are closed by hemi-spherical plates secured by riveting or welding.

Riveted on to the bottom of each water drum are two or three supporting brackets, known as boiler feet. The boiler feet rest on

a flat surface on the boiler bearer on each side and are held down by keep-plates, which keep the boiler in position, but allow for some movement to provide for expansion. The steam drum is supported by the generator tubes. To prevent displacement of the steam drum in the event of a collision, the back end of the drum is attached to a bulkhead by what is called a ramming stay. This stay prevents serious displacement of the drum, while at the same time allowing for expansion. A manhole is provided in the front end of each drum, to allow of access for internal cleaning.

Feed water is admitted to the steam drum, to maintain a water level in the boiler sufficiently high to ensure that all the generator tubes shall be full of water. As the generator tubes nearest to the furnace receive more heat than those remote from the furnace, there is a circulation of water down the outer rows and up those near the furnace on each side. The tubes which are exposed to the most intense heat are the two rows nearest the furnace on each side. These are known as fire-row tubes, and they are made of larger diameter than the remainder, to ensure that they shall receive an adequate supply of water.

10. Admiralty Superheater Boiler.—This is a three-drum water-tube boiler fitted with superheaters. Fig. 4 shows part of the boiler viewed from the front, with the casings removed to show the tubes.

A space is formed among the generator tubes on each side, by arranging the four or five rows of tubes nearest the furnace with a bend in one direction, while the remainder are curved in the opposite direction. In each of these two spaces are fitted a number of horizontal " U " tubes through which the steam is passed in order that it may be superheated. In the Admiralty superheater shown in Fig. 4 the open ends of the " U " tubes are expanded into tube holes in two cylindrical headers, fitted on the front of the boiler and supported from the steam and water drums.

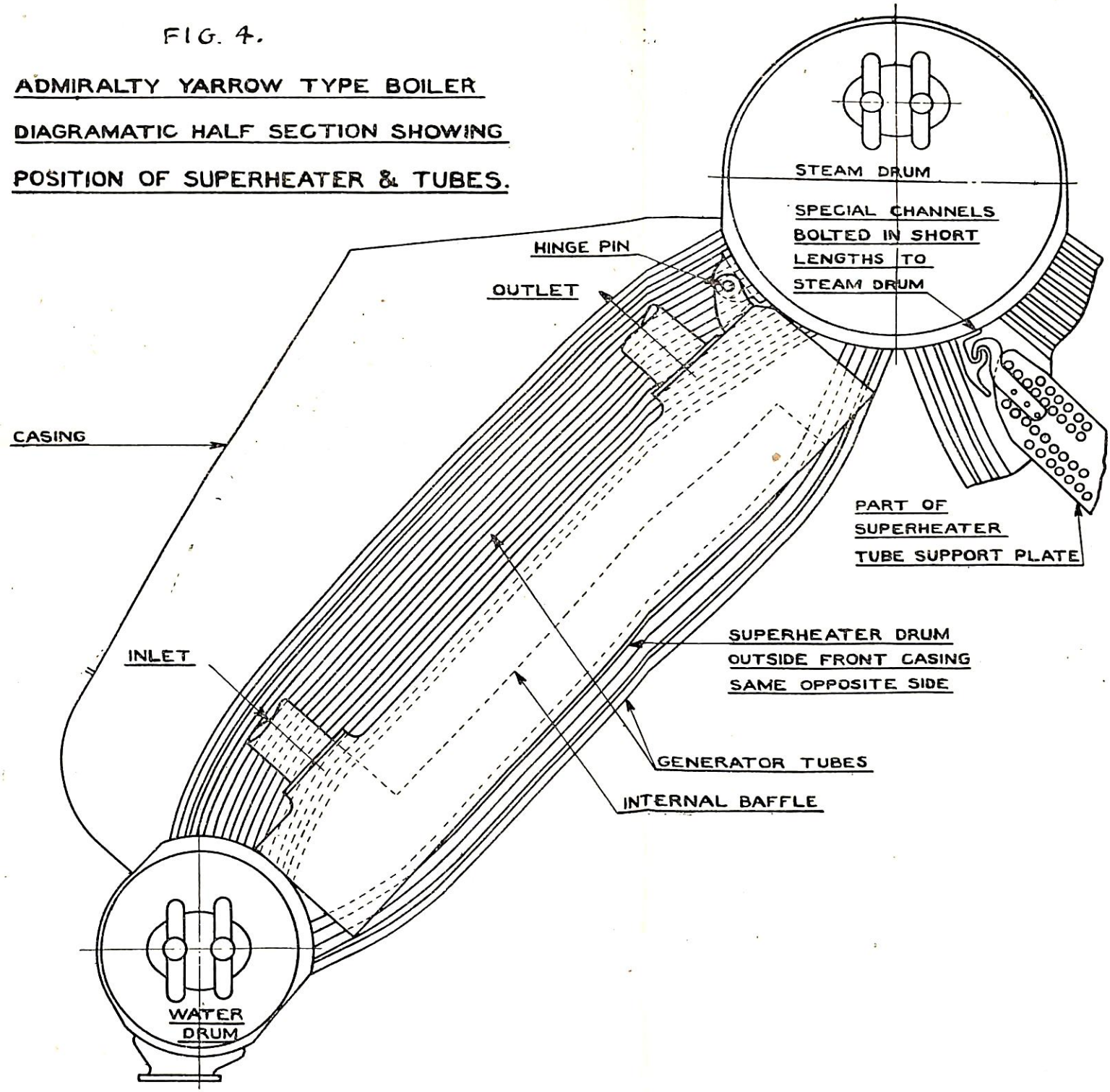
The superheater tubes are supported at the front end by the header, and at the back end by a plate support through which they are threaded. A hook at the top end of this support is free to slide in a channel bolted on to the bottom of the steam drum, and a toe at the bottom end rests on an angle bolted to the water-drum. In Fig. 4 the superheater header is shown in place on the left-hand side, while on the right-hand side the header is omitted to show the plate support.

The space inside each superheater header is divided into two halves by means of a longitudinal and two semi-circular transverse baffles, and each superheater tube is so arranged that one open end

FIG. 4.

ADMIRALTY YARROW TYPE BOILER

DIAGRAMATIC HALF SECTION SHOWING POSITION OF SUPERHEATER & TUBES.



To face page 12

is in one half of the header and the other open end in the other. The saturated steam formed in the generator tubes rises to the top of the steam drum and passed from here through a pipe to the bottom of one of the superheater headers. To reach the outlet from the superheater header the steam must flow through the superheater tubes, and while doing so it receives heat from the hot gases passing across the outside of those tubes. Portable plates on the front casing allow of examination of the ends of the superheater tubes adjacent to the header. For complete examination, or to replace a tube in an Admiralty superheater, the whole superheater must be withdrawn from the boiler.

In the M.L.S. superheater, which is being fitted in the latest ships, any one superheater tube can be removed and replaced without withdrawing the whole superheater. Two headers are fitted on each side of the boiler, the inlet end of each superheater tube being attached to one header and the outlet end to the other. The joints between the tubes and the headers are made by spherical nipples on the ends of the tubes held into conical seatings in the headers by strongbacks and studs.

11. Position of Superheater.—By fitting a superheater so that it is only separated from the furnace by four or five rows of generator tubes a high degree of superheat at all powers is obtained, but care is necessary to prevent overheating of the tubes when lighting up. Not more than one oil fuel sprayer should be used, until the stop valve fitted at the outlet side of the superheater has been opened, and a flow of steam through the superheater tubes ensured. In some boilers in small ships, where a high degree of superheat is not required, the superheaters are fitted outside the outer rows of generator tubes. In these boilers a superheater steam drum is fitted horizontally above the water drum on each side of the boiler, and the superheater tubes extend from one side of a horizontal baffle in each drum, up to a point near the top drum, and down to the other side of the superheater drum.

12. Brickwork.—Special bricks, known as fire-bricks, are used to protect the steel plates bounding the furnace of a water-tube boiler from the intense heat of the flame. The plates are first covered over on the furnace side with a layer of asbestos millboard and the bricks are built over this, each brick on the sides, front and back of the furnace being secured by a bolt in the centre of the brick. Two methods of bolting up the bricks are employed. In one method there is a hole right through each brick, the hole

being enlarged on the furnace side so that the head of the bolt will be below the surface. The heads of the bolts are protected by filling the recesses with a mixture of fire-clay and crushed fire-brick mixed with a little water. This is known as stopping, and is rammed firmly into the recess in each brick. The other method is to employ a form of brick known as Wildish bricks. Each Wildish brick has a recess in the back which is so shaped, that the special bolt used is locked, if after entering the head in the recess it is turned a quarter of a turn. As with Wildish bricks, there is no hole through the brick stopping is not required. The nuts on brick bolts must not be screwed up tight, as the bricks are easily cracked.

A binding material, similar to stopping but made with more finely crushed fire-brick and a little more water, is used between the bricks.

In oil-fired water-tube boilers the brick-pans, which form the bottom of the furnace, are covered with millboard and two layers of fire-bricks, arranged so that the bricks in the upper layer cover the joints between the bricks in the lower layer. Special bricks, known as cone bricks, are used around the holes in the furnace front through which the oil fuel is sprayed in.

In cylindrical boilers, as the walls of the furnace form part of the heating surface, they are not lined with fire-bricks. Bricks are used only to protect the furnace front and also the back seams where necessary.

It is a common practice to wash over new brickwork with bonding material, thinned down with water until it is suitable for application with a brush. The brickwork should always be examined after a boiler has finished steaming, and any defective bricks and bolt hole stopping renewed.

13. Air Preheaters.—In order to transfer some of the heat going to waste up the funnel to the air used for the combustion of the fuel in a boiler, air preheaters are fitted in the uptakes when there is space available and the additional weight can be accepted. The preheaters are fitted between the top of the boiler on each side and the base of the funnel. They may be either of the tubular or plate type. In a tubular preheater the flue gases pass through a number of tubes made of thin steel plate, and the air flows across the outside of these tubes. Plate-type preheaters are built of a number of thin corrugated steel plates, in such a way that each plate has flue gases passing over one side and air on the other side ; heat is transferred through the plates from the hot flame gases to the air. The air side of each preheater is open at the front end to the boiler room, and connected at the back end to an air space

down the back of the boiler and under the brickpans. From the air space under the brickpans air can pass to the air box on the front of the boiler, and hence into the furnace. In some boilers air can also reach the air box on the boiler front by flowing through air spaces on the side casings.

By flowing through the preheater, and through the air spaces down the back and under the boiler, the temperature of the air entering the furnace is raised about 100° F. above the temperature in the boiler room. The preheaters fitted in some cruisers are only large enough to supply air for about half the sprayers of each boiler; when steaming at high power the additional air required is admitted through air flaps on the boiler front.

A certain quantity of steam is formed by the combustion of both oil fuel and coal. If the temperature of the metal surfaces in a preheater are cold, this steam will be condensed on the surfaces, and rusting and corrosion will take place. The fact that there are traces of sulphur in all fuel increases the rate of attack on the steel if the surface is damp. The temperature of the steel in a preheater will be about the mean of, the temperature of the air passing on one side of the steel plate or tube, and the temperature of the flue gases passing on the other side. Condensation will not take place if the mean, of the temperature of the air entering, and the temperature of the gases leaving, is not less than 170° F. A distant reading thermometer is fitted to record the temperature of the flue gases leaving the preheater. Doors are provided on the air trunks on the back of the boiler through which the air may be allowed to enter, thus byepassing the preheater. These doors should always be opened when lighting up, and also when only one sprayer is in use if the flue gases are being cooled to a temperature at which condensation may be taking place.

14. Priming.—The steam leaving the surface of the water in a boiler carries with it a certain amount of water in the form of small particles. Under certain conditions the quantity of water carried over with the steam may become excessive, and the boiler is then said to be priming. Water-tube boilers are much more likely to prime than cylindrical boilers, on account of the smaller water surface from which the steam is being evolved, and the greater rate of forcing to which these boilers are subjected. The cause of priming may be either too high a level of water in the boiler, or the water in the boiler containing an undue amount of impurities. These impurities may cause foaming, and large quantities of water will then pass over with the steam. Under these conditions it will be very difficult to maintain the correct level of water in the boiler, and if a superheater is fitted the temperature of the superheated steam will drop. Priming may cause damage to the machinery,

reciprocating engines being particularly liable to suffer if the steam entering the cylinders contains an undue quantity of water. Even if no damage is done, priming may cause a reciprocating pump to stop. The greater the quantity of steam being generated in a boiler, the more likely it is to prime. Therefore in the event of priming the rate at which fuel is being burnt should be reduced, particular attention paid to the water level in the boilers, and every available means employed to drain water from the steam before it reaches the engines.

15. Purity of Feed Water.—If the water fed to a boiler contains solids in solution, the heating and evaporation of the water will cause some of these solids to be deposited on the heating surfaces in the form of scale, while others will remain in solution and cause a rise of density of the water in the boiler, and possibly corrosion of the steel surfaces. In a water-tube boiler it is difficult to remove scale from the inside of the tubes, especially if it be a hard scale. If such scale be allowed to accumulate, it will form an insulating layer between the metal of the tubes and the water inside. Not only will this impair the efficiency of the boiler by interfering with the transfer of heat from the furnace gases to the water in the tubes, but also the tubes near the furnace are liable to become overheated, possibly to such an extent that they become red-hot. When steel is red-hot it is soft, and a red-hot boiler tube will be unable to resist the internal pressure, and will therefore swell and burst. Even if overheating does not result in such serious damage, the tubes will be distorted, and leakage will probably occur at the expanded ends. Also if there is any oil in the feed water, this will collect on the tubes, and being a poor conductor of heat, may cause overheating.

The fresh water from all shore supply mains contains some solids in solution, and such water is not suitable for use in water-tube boilers unless it is subjected to special treatment to remove scale-forming substances. For the water-tube boilers of H.M. ships only pure distilled water must be used. Care must be taken that the feed water does not become contaminated with sea water, due to leakage of condensers, etc., and that any trace of oil that may be present is removed.

16. Air in Feed Water.—If a piece of bare iron or ordinary steel is left out in the open air it will corrode, and rust will be formed on the surface. The damper the air the more rapid the corrosion. This corrosion is due to the fact, that in the presence of moisture, the oxygen in the air will attack iron or steel, forming an oxide of iron. When this action takes place in the open air the majority of the oxide formed will be red oxide of iron, which is commonly known as rust. If a piece of steel is placed in water, so that it is

not directly in contact with the air, it will still corrode, but the action will not be so rapid, and most of the oxide formed will be black oxide of iron. The action in this case is due to a little oxygen from the air dissolving in the water and so attacking the steel. As the oxygen in the water is used up a little more goes into solution, and the action will continue if the air has access to the water. To prevent corrosion of the internal surfaces of boilers, when not in use, it is the practice to expel the free air, by completely filling the boiler with fresh water. This is known as pumping the boiler up to W.W., and it will only be completely effective in preventing corrosion if the water is de-aerated, *i.e.*, free from air in solution. In many modern ships means are provided to de-aerate the water for boilers, and apparatus is supplied to enable the amount of oxygen present to be ascertained by what is known as the Winkler test. (*See* articles 187 and 188.)

17. Addition of Lime to Feed Water.—The feed water used for boilers must not have any acid properties, because acid water promotes corrosion of the internal surfaces of a boiler. Pure distilled water is not acid, but it may easily become so by the absorption of traces of impurities from the atmosphere and other sources. To neutralise any harmful acid that may be present in the feed water, sufficient lime is added to maintain the water in the boilers in a slightly alkaline condition ; more lime should not be used than is necessary to do this.

Lime for feed water is supplied, in the form of powdered slaked lime, in air-tight drums. The drums should be kept tightly closed when not in use, as the slaked lime deteriorates if left exposed to the air. Lime is always added in the form of lime water, to ensure that only the finest particles are used. To prepare the lime water, take ½ lb. of slaked lime, and tie it up in a piece of towelling, or other suitable material. This amount of lime is sufficient to prepare five or six bucketfuls of lime water. The lime tied up in the towelling is moved about in each bucketful of distilled water until a milky liquid is produced. Afterwards any lime left in the towelling may be treated as impurities and thrown away. This milky solution, after straining, is introduced into each boiler before pumping it up after cleaning, or into the feed-water tanks.

18. Test for Alkalinity.—To test that sufficient lime has been added to make the water alkaline, a drop of phenol-phthalein solution is added to a clean test-tube filled with the water to be tested ; if it is alkaline the water will assume a pinkish colour. If the water contains insufficient lime no change will occur on adding the phenol-phthalein.

The water in boilers in use should be tested for alkalinity daily,

or at such intervals as found necessary to ensure that it is maintained in an alkaline condition.

Phenol-phthalein solution is highly inflammable and must not be exposed near a naked light.

19. Detection of Salt in Feed Water.—The feed water can become contaminated with salt water in a number of different ways, such as, a leaky condenser or cooler on the feed circuit, a leak into the feed water tanks, or contaminated water admitted to the tank from the distilling plant. In modern ships electrical instruments, called salinometers, are provided to indicate the presence of salt in the feed water withdrawn from the condensers, and also in the fresh water made in the distilling plant. Too much reliance should not be placed on these instruments, and tests of the feed water should be made with silver nitrate at least every four hours.

Take a clean test tube, wash it out and fill it with the water to be tested. Then from a special drop bottle allow one or two drops of silver nitrate to drop into the water. If salt is present in the water, the addition of silver nitrate will cause a milky looking cloud. If, after waiting a few moments, no change can be seen on holding the test tube in a good light against a dark background, the water is free of salt. The tube should not be inverted with a thumb over the end, as there may be enough salt on the skin to give a slight cloud.

This test is not as sensitive if the water is hot, the temperature should not exceed 100° F. If there is any lime in the water, this may give rise to a cloud on adding silver nitrate. Therefore on testing water from the boilers or reserve feed tanks, where there may be lime, a few drops of nitric acid are added first to prevent the formation of a cloud due to the lime.

20. Oil in Feed Water.—Reciprocating engines require a certain amount of internal lubrication, and the exhaust steam from such engines will contain traces of the oil used for this lubrication. Most of this oil can be removed after the steam has been condensed, by passing the water through filters or grease extractors. Even when the filtering material of these feed water filters is clean, all the oil may not be intercepted. Any oil remaining in the feed water, after it has passed through the filters, will pass into the boilers.

If the quantity of oil used for internal lubrication is reduced to a minimum, and the filters are kept clean, the amount of oil that passes into the boiler will be too small to be noticeable. *Watchkeepers should not admit oil to the cylinders, or apply oil to the piston and valve rods, of reciprocating engines, unless specially directed to do so* (see article 15). Feed water filters should be cleaned frequently. When the filtering material is towelling this may be boiled in soapy water or in a solution of not more than 4 ozs. of Basol 77

to a gallon of water. After boiling, the towelling must be rinsed in hot clean water. The sponges fitted in some filters should not be boiled.

No internal lubrication is used for turbines, and in ships where the main engines are of this type, only the exhaust from reciprocating auxiliary engines is liable to contain oil. As the dirty exhaust steam from these auxiliaries is not generally admitted to the main condensers, there is no necessity to filter the condensate from these condensers. (*See* article 168.)

21. Density of Boiler Water.—The scientific definition of density is the weight of unit volume. It can be stated in pounds per cubic feet, and other convenient units. Specified gravity is a comparison of the density of a substance with the density of water at 4° C. If a solid substance is dissolved in water the density of the liquid will be increased, and a measure of the density will indicate the amount of this solid in solution.

The most convenient method of measuring the density of a liquid is by means of a hydrometer. These can be designed to read the specific gravity of the liquid, or to indicate, on some convenient scale, an increase in the density of the liquid for which they are to be used.

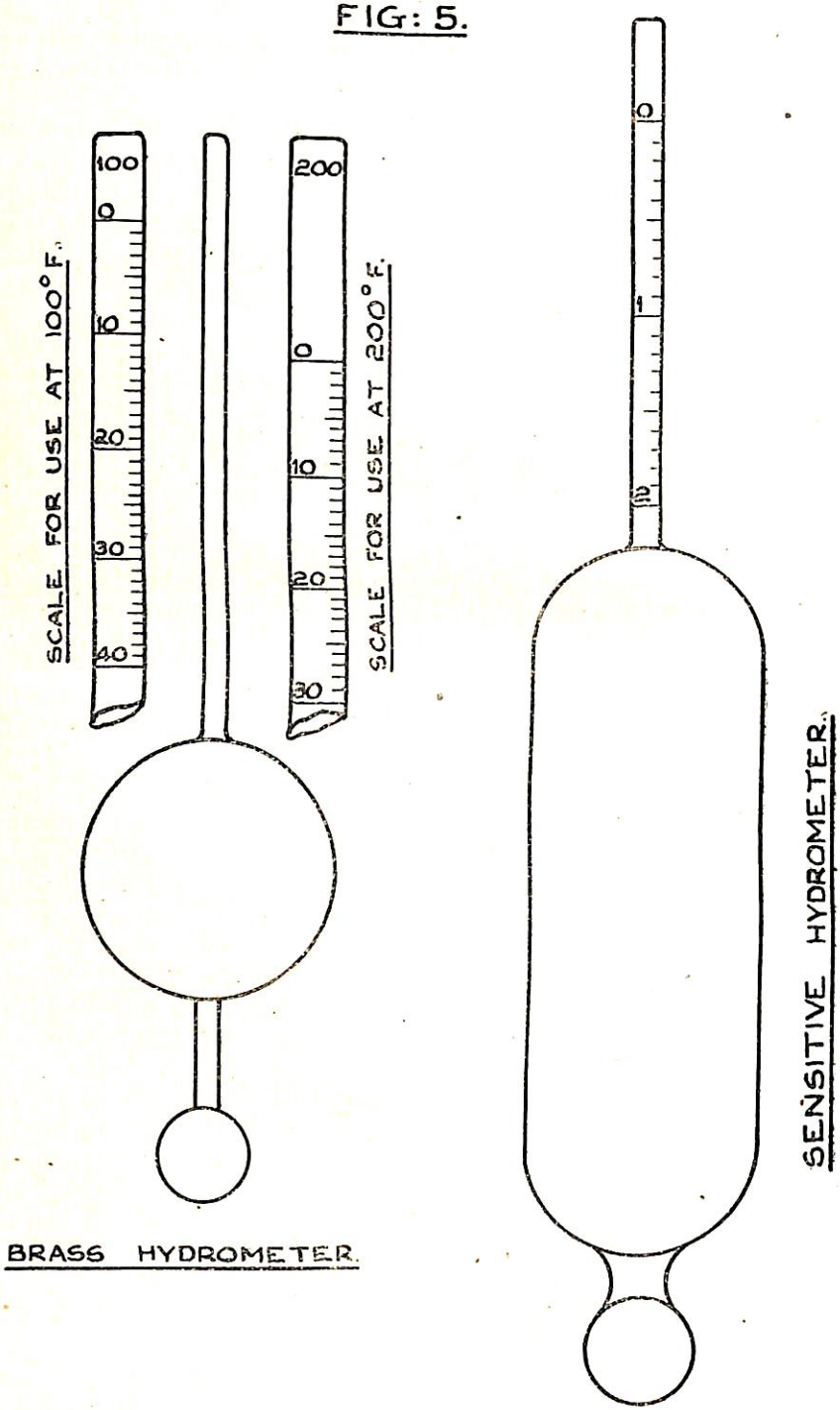
Fig. 5 shows two hydrometers of the latter type, made for measuring the density of boiler water. They are weighted at the bottom, so that they float upright in the water. The scale of the brass hydrometer is arranged, so that, when floating in pure fresh water the zero reading is level with the surface, and when floating in sea water the reading 10 is at the surface. As water expands when its temperature is raised, and therefore has a lower density, the position at which the zero mark and other readings must be placed will depend on the temperature of the water. This brass hydrometer has two scales, one for use in water at 100° F., and the other for water at 200° F. It was designed for measuring the density of boilers when salt water feed was used, and is now only used for evaporators.

With modern boilers it is necessary to be able to measure very slight increases in the density of the water, and the sensitive hydrometer was introduced for this purpose. It will be noticed that it only reads up to two degrees, and that each degree is divided into tenths. For accurate results the readings must be taken when the temperature of the water is exactly 100° F.

The density of the water in the boilers should be taken every four hours at sea, and daily in harbour. An increase in the density indicates that impure feed water is being used, and this should be reported in order that the necessary steps may be taken.

With water-tube boilers the maximum allowable density is

FIG: 5.



BRASS HYDROMETER.

SENSITIVE HYDROMETER.

three-tenths of a degree, since such boilers will prime if the density is greater than this.

22. Cleaning and Preservation of Boilers.—The efficiency of boilers, and the length of time that they will remain fit for service, depends on the attention paid to the keeping of the heating surfaces clean and to the prevention of internal and external corrosion. The importance of using only distilled water, maintained in a slightly alkaline condition by the addition of a small quantity of lime, has been mentioned, as has also the harmful effects of oxygen or oil in the feed water. The method now employed to supply boilers with de-aerated water is dealt with in a later chapter.

All boilers are emptied and opened out for examination and cleaning of the internal surfaces at regular intervals. The number of hours that a boiler may be steamed between internal cleanings depends on the type of boiler, and on the likelihood of there being any oil in the feed water. For main boilers 500 to 750 hours' steaming is allowed, while low-pressure auxiliary boilers may do up to 2,000 hours. Irrespective of the amount of steaming that has been done, all boilers of H.M. Ships in service must be examined internally once every quarter.

In addition to the internal cleaning of boilers, it is necessary to remove the soot which accumulates in the uptakes, preheaters and in the smoke tubes of cylindrical boilers, or around the outside of the tubes of water-tube boilers. In oil-fired boilers it normally suffices if boilers are thoroughly cleaned externally at the same time that the internal cleaning is carried out, but with coal-fired boilers external cleaning must be done after every few days of steaming. Soot falling or swept from the upper portion of three drum boilers collects on the top of the lower drums. Special doors are provided on the lower part of the front and side casings of these boilers, so that this soot can be removed, either with special brushes or by blowing with air. In modern ships, soot blowers are fitted, by means of which, while a boiler is steaming, a steam jet can be directed onto the tubes and also into the air preheater, to dislodge the soot (*see* article 42). The operation of a soot blower will eject a certain amount of soot from the top of the funnel. Soot blower should be used after an order to make smoke has been carried out, and at other times only when ordered by the Engineer Officer of the Watch. The absorption and retention of moisture by soot has caused serious external wastage of the tubes of three-drum boilers.

To prevent as far as possible the external surfaces of a boiler becoming damp from rain coming down the funnel, gutters with drains to the bilge are fitted in the uptakes. Screwed plugs are

fitted on the drain pipes from these rain catchments, for clearing them if they become choked. At the end of each drain pipe is a filter, to prevent soot being carried into the bilges. The silicate of cotton, with which these filters are packed, should be renewed when necessary. In harbour, when boilers are not alight, the tops of the funnels should be covered over with canvas funnel covers.

Two methods are adopted to prevent internal corrosion of boilers when not in use. The normal method is to pump the boilers up to W.W., as mentioned in article 16. This should be done after steaming, as soon as the pressure has died down, and when the boiler is cold it should be topped up until water escapes from the air cocks, which should then be shut (*see* article 188). When, however, a boiler will not be required for some months, it is better to empty it, dry it out by placing airing stoves in the furnace; water lying in superheater tubes should be blown out with air. After drying the boiler is closed up with trays of quicklime in each drum. The lime absorbs the moisture from the air, and thus prevents corrosion. Boilers preserved in this way are said to be empty closed and limed, or for short, E.C.L. A method of preservation occasionally employed is to use trays of burning charcoal instead of quick lime. The charcoal combines with the oxygen in the boiler, so that there is not free oxygen left to attack the steel. When opening out a boiler which has been preserved in this manner, particular care must be taken that no one is allowed to enter the boiler until it has been thoroughly ventilated and tested with a safety lamp, as laid down in Chapter VI.

In cold weather precautions must be taken to prevent the water freezing in boilers which are not alight. The boilers may be run down to W. and kept warm by means of airing stoves in the furnaces, or if the boilers will not be required, they should be emptied and put into a state of preservation.

23. Procedure for Internal Cleaning.—A boiler to be cleaned is run down, either to the reserve feed tank, or to the bilge if the water is very dirty. In the former case the water is passed through a strainer to remove any sediment. It will be necessary to open an air cock on top of the boiler, to allow air to replace the water. Before opening up the boiler a water-gauge cock should also be opened, to make quite sure that there is a complete absence of pressure or vacuum in the boiler.

The normal practice, when a steaming boiler is due for internal cleaning, is to allow it to cool down after being shut off, and to run it down in the usual manner. Should circumstances arise which necessitate the boiler being ready for cleaning earlier than would be obtained by the normal procedure, the Engineer Officer

may order the water in a water-tube boiler to be blown out to the sea. (*Note.*—Blowing into a cylindrical boiler in this manner is only allowed in cases of extreme urgency as such a practice is liable to cause leaky tubes and joints.)

When blowing out a boiler the following precautions should be taken :—

(i) Blowing down should not be commenced until the pressure in the boiler is down to about 80 lb. per square inch.

(ii) Blowing down should be stopped while there is sufficient pressure in the boiler to prevent the entry of water from the sea.

(iii) After blowing out the boiler should be allowed to cool until no pressure exists in the boiler, when air cocks and gauge-glass cocks should be opened and running-down valves opened to bilge. (*Note.*—The cooling of the boiler must not be hastened by admitting air to the furnace.)

(iv) After a reasonable period the manhole doors on the steam and water drums may be opened. It is important that the top door be opened first, and that men be warned to keep clear of this opening while the bottom doors are opened. On account of the temperature of the boiler there will be a rush of air through the boiler when a lower door is knocked in, and a gush of steam and hot air from the steam drum manhole.

The possibility of there being an explosive mixture present in the boiler should be borne in mind, and on removal of the manhole doors, no naked light must be brought near, and no rating allowed to enter before the boiler has been ventilated thoroughly. To dry out the boiler airing stoves are placed in the furnace, and these should be used as necessary during the time that the boiler is open, to prevent condensation on the steel surfaces.

If other boilers are alight, or may be lit up, the stop valves, feed valves and other valves or cocks, through which steam or hot water could enter the boiler being cleaned, are to be shut and secured against being opened accidentally. Where the arrangement of the pipes and valves permits, there should be two shut valves between the man in the boiler and any pipe containing steam, and a drain cock should be open on the length of pipe between these valves.

All fittings inside the boiler are removed for cleaning, and the internal surfaces of a boiler are scrubbed clean with wire scrubbers, scrapers and light chipping hammers being used if necessary in cylindrical boilers. Special wire brushes are used for the tubes of water-tube boilers. Men working in water-tube boilers must not be allowed to take in with them anything which may fall into the tubes, and all articles used in the boiler should be mustered and

accounted for before the boiler is closed. Before replacing the internal fittings and closing up a boiler after internal cleaning, it must be ascertained that the orifices for pressure gauges, water-gauge mountings, etc., are clear, and all the tubes of water-tube boilers must be sighted through, or searched with a wire, to ensure that there is no obstruction in any tube. Except in the case where a boiler is to be kept E.C.L., it is washed through and pumped up to W.W. after cleaning, lime water being added as necessary. When the boiler is full the air cock is shut, and a water pressure, up to the working pressure, is put on the boiler for a few minutes, to ascertain if all the joints are tight.

Where any grease is found in a boiler, and this cannot be completely removed by the ordinary methods of cleaning, the boiler should be boiled out, first with a solution of 7 lb. of common soda or 2½ lb. of soda ash to each ton of water, and then with distilled water. Special compounds, such as Snowdrift Zinc Fluid or Boiler Disincrustration Powder, are sometimes added to the water in cylindrical boilers, to facilitate the removal of scale from parts of the boiler not readily accessible.

24. Tests of Boilers.—In spite of the precautions taken, there will occur a certain amount of corrosion and wastage of the steel used in the construction of a boiler. Steps must be taken to ensure that any parts of a boiler which become reduced in thickness are renewed, before there is any chance of these parts failing when the boiler is in use. For this reason what is known as a wear-and-waste test, or drill test, is carried out when the boilers have been n use from 2½ to 3 years, and subsequently at intervals of 1½ to 2½ years, depending on the service for which the boilers are used. A very thorough examination is made of all the boilers, and some tubes are removed from certain selected boilers, and cut up to ascertain their internal condition. Where wastage of any plate is noticeable or suspected, a hole is drilled through the plate, in order that its thickness may be measured. Such holes are afterwards closed by a screwed plug riveted over. On completion of the wear-and-waste test, all boilers are subjected to a test by water pressure, up to what is known as the test pressure. This test pressure is one and a half times the safety-valve load for working pressure of 180 lb. per square inch and above, and up to twice the safety-valve load for lower working pressures. As an additional precaution, a water-pressure test to the test pressure is carried out annually, the first test being made when the boilers are two years old. If a boiler has not been used for six months or longer, it is tested by water pressure, before steam is raised.

When applying the test pressure to a boiler, care must be taken that any water which may leak past the stop valve does not reach

a pipe containing steam. Two valves should be shut between any such pipe and the boiler, and a drain cock open between the two valves. The safety valve on the boiler must be gagged, the water-gauge glasses, and any pressure gauge which does not read up to the test pressure, shut off. Care must be taken that the test pressure is not exceeded. A special pressure gauge, called a Duplex gauge, is fitted to a boiler before applying the test pressure.

CHAPTER III.

BOILER MOUNTINGS AND THEIR OPERATION.

The following are the mountings fitted on a boiler :—

25. Internal Steam Pipe.—When water is boiled rapidly, as is the case in boilers, there is a tendency for globules of water to become suspended in the steam generated. Water passing over with the steam might cause damage to the engines, and when superheaters are fitted, an undue amount of water entering the superheater will reduce the temperature of the steam, and hence the advantage gained by superheating. In order to ensure that the steam leaving a boiler is as far as possible free from globules of water, it is collected in an internal steam pipe. This is a pipe, fitted in the steam drum, through which the steam must pass to leave the boiler. One end of the pipe is closed and a large number of narrow slots are cut in the upper surface. At its lowest point of the pipe is a drain hole, so that any water that collects at the bottom can fall back into the steam drum.

26. Stop Valve.—The valve fitted to control the passage of steam from a boiler to the main steam pipe, and thence to the main engines, is called a main stop valve. There are sometimes two main stop valves on each boiler, one passing steam to a main steam pipe lead along the port side of the ship, and the other to a main steam pipe on the starboard side. In addition to the main stop valve or valves, a smaller stop valve is generally fitted to supply steam to the auxiliary machinery. In a boiler with superheaters the stop valves for main and auxiliary turbines are fitted on the outlet side of the superheaters, and if steam is also required for reciprocating auxiliaries a saturated stop valve is fitted on the steam drum.

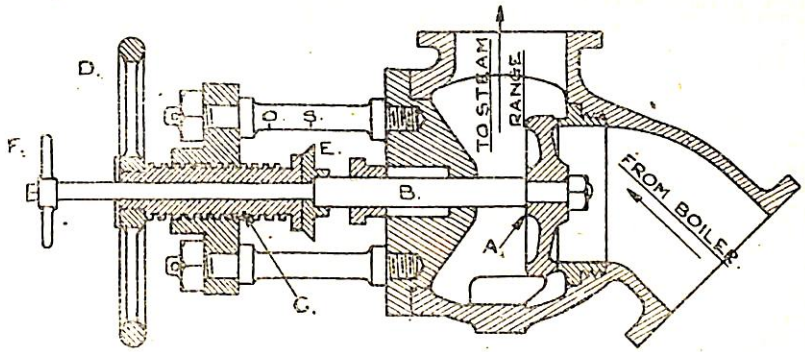
Where the installation consists of more than one boiler which can be connected to the same steam pipe, it is to be noted that if one boiler is damaged by means of gun fire, or other means, the steam from the other boilers would pass into it, thus adding to the dangers from the escaping steam, unless the stop valve on the damaged boiler is shut immediately. To lessen the above mentioned danger, where more than one boiler is installed, boilers are generally fitted with self-closing stop valves. These valves are so designed that they may be expected to close if steam passes through them in the wrong direction, as would be the case if steam entered a damaged boiler from the others in use.

Fig. 6 shows a self-closing stop valve. The valve A is attached to one end of the spindle B, and the other end of the spindle is made an easy fit inside the screwed sleeve C. The valve is kept concentric with its seating; either by a guide under the valve as shown in sketch, or by an extension of the spindle on the boiler side of the valve working in a small circular guide supported by ribs.

Turning the handwheel D in a clockwise direction, causes the end of the screwed sleeve to bear against the collar on the spindle B, and closes the valve. When the indicator plate E is opposite the mark S the valve is shut.

To open the valve, a U-shaped distance piece is fitted between the handwheel and the T handle F, then by turning the handwheel

FIG: 6.



SELF-CLOSING STOP VALVE.

in a counter-clockwise direction the valve is drawn away from its seat. If the sleeve C is screwed back without the valve opening, the pressure in the boiler may cause the valve to open suddenly and fracture the valve box. After opening the valve the distance piece must always be removed.

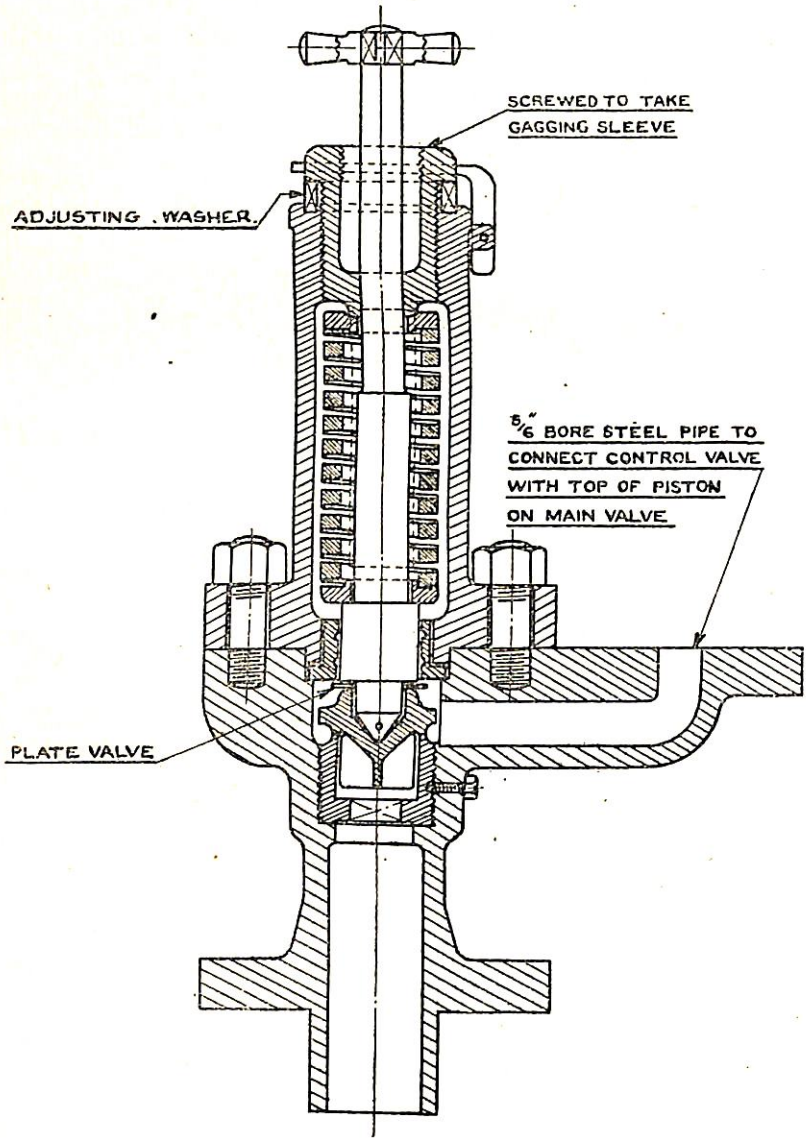
In the event of a tube bursting in the boiler on which the valve is fitted, the rush of steam into the boiler from other boilers alight will close the valve. These valves are always fitted with the spindle horizontal. The gland must be carefully packed, so that the spindle can slide freely through it.

27. Safety Valves.—These are spring-loaded valves, fitted on the boiler, which lift and allow steam to escape, should the pressure in the boiler rise above the designed working pressure. A waste steam pipe is fitted up the outside of the funnel, to carry the

escaping steam clear of all the personnel. There are generally two safety valves, one adjusted to lift at the working pressure, and the other at 3 lb. above working pressure. Hand lifting gear is

FIG. 7.

PILOT VALVE OF COCKBURN MACNICOLL FULL BORE SAFETY VALVE.


SCREWED TO TAKE GAGGING SLEEVE
ADJUSTING WASHER.
5/6" BORE STEEL PIPE TO CONNECT CONTROL VALVE WITH TOP OF PISTON ON MAIN VALVE
PLATE VALVE

provided for use in case of emergency. It should be worked daily to ensure that it is free, but not sufficiently to lift the valves.

The safety valves must be able to pass all the steam the boiler produces at full output, without the pressure rising more than 10 lb. above the working pressure. This requirement is best fulfilled by fitting what are known as full-bore safety valves. In this type of valve a small spring-loaded pilot valve controls a large main valve, which opens wide should the pressure in the boiler rise above the pressure at which the pilot valve is set to lift. Attached to the main valve is a piston fitted in a cylinder closed at one end, the piston being larger in diameter than valve. A passage from the closed end of the cylinder leads to the space above the pilot valve, which is shown in Fig. 7. A light spring is fitted to keep the main valve on its seat when the boiler is not alight. When the boiler is in use the steam pressure acts on the back of the main valve. When the pressure in the boiler rises sufficiently to overcome the compression of the spring, the pilot valve lifts and allows steam to enter the space above this valve. The rush of steam to escape to the boiler room round the circumference of the valve spindle lifts the plate valve and thus prevents the steam escaping. The pressure above the pilot valve and behind the piston of the main valve, therefore rises sufficiently to open the main valve against the boiler pressure. When the pressure of the boiler has fallen sufficiently, the spring returns the pilot valve to its seat. The plate valve is pushed down, the steam from the space above the pilot valve, and from the space behind the piston of the main valve, escapes to the atmosphere around the circumference of the pilot valve spindle, and the main valve closed.

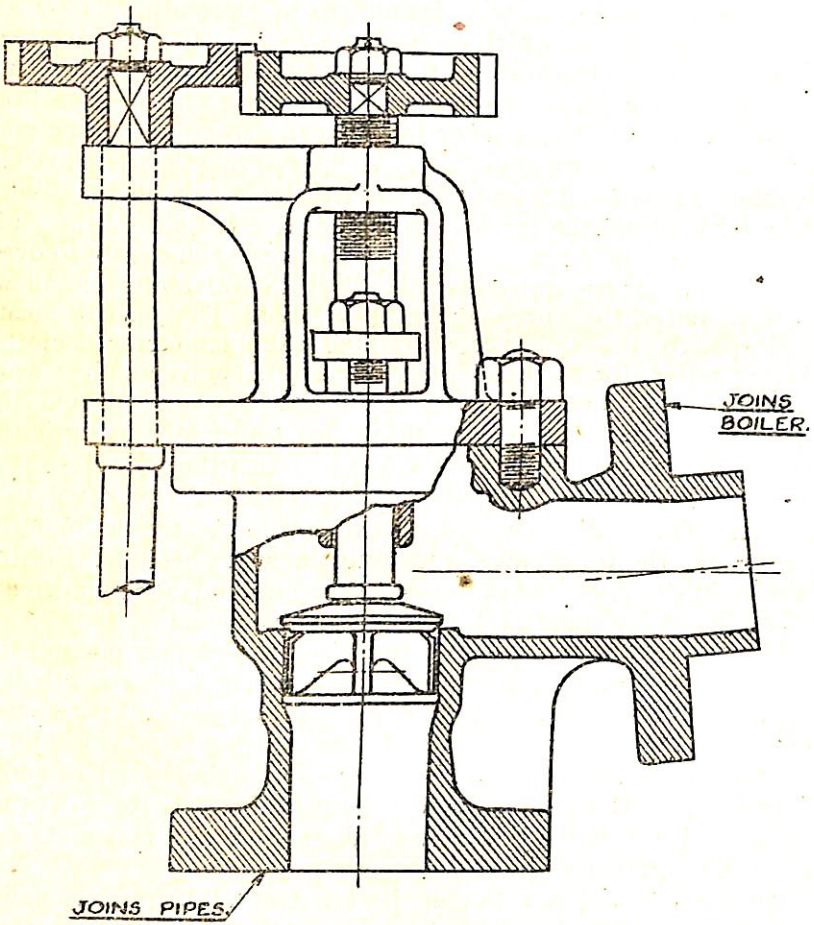
The pilot valve is adjusted to lift at the correct pressure by means of the compression screw. An adjusting washer is fitted so that the compression on the pilot valve spring cannot be increased when the boiler is in use. A small cap or gag is provided to fit over the end of the pilot valve spindle, after removing the T handle. By this means the pilot valve can be held down on its seat, when it is desired to test the boiler by water pressure to a pressure above the working pressure.

On the first boilers with superheaters two full-bore safety valves were fitted on the steam drum and two on the outlet side of the superheaters, all controlled by pilot valves on the steam drum. To ensure a flow of steam through the superheater tubes, it is arranged that the superheated steam safety valves lift before, and close after, the saturated steam safety valves. In modern superheater boilers safety valves are fitted only on the outlet side of the superheaters, the valves being controlled by pilot valves on the steam drum. To cover the possibility of a choke in the control

pipe, a third pilot valve is fitted to operate a whistle alarm. This sentinel valve is set to lift at 10 lb. above working pressure.

28. Feed Check Valves.—Two screw down non-return valves, known as the main and auxiliary feed check valves, are fitted on the steam drum, to control the supply of feed water to the boiler;

FIG. 8.



FEED CHECK VALVE – NON RETURN.

the water level being shown by the water gauges. The main feed check is generally fitted on the right-hand side, and the auxiliary on the left. Fig. 8 shows a section through a feed check valve. The spindle, which can be worked from the floor plates, and in new ships from the valve as well, merely limits the amount the

valves can open. The feed supply pressure must be greater than the pressure in the boiler to lift the valve.

After passing through the feed check valve the water enters an *internal feed pipe* fitted inside the steam drum. The end of the pipe remote from the feed check is blanked and large number of holes are drilled along the upper surface. This pipe distributes the relatively cold water evenly throughout the length of the drum.

Feed water is normally supplied by the *main feed pump* through the main feed check, the rate of supply being controlled automatically or by hand. In case of a failure of the main feed supply an *auxiliary feed pump* is provided. This pump supplies water to the auxiliary feed check, which must be controlled by hand. In modern ships, where a feed water heater is fitted between the main feed pump and the main feed check, a cross connection is provided between the main and auxiliary feed pump systems. This enables the auxiliary feed pump also to supply through the feed heater and automatically controlled main feed regulator.

It is of the utmost importance when steaming, that the auxiliary feed system should be ready for immediate use. The evaporation is so rapid at full power, that, if the feed supply fails, the level of the water in the boiler will fall about six inches in half a minute. The auxiliary feed pumps are invariably fitted in the boiler rooms under the direct control of the boiler-room watchkeepers, while the main feed pumps are generally in the engine room.

In modern destroyers the main feed pumps, which are in the engine room, are driven by steam turbines, while the auxiliary feed pumps are reciprocating, and are only of sufficient capacity to feed the boilers at half power. When steaming at low power, the auxiliary feed pumps are sometimes used to feed the boilers and the main feed pumps reserved as a stand-by, as this is more economical. A request to start the main feed pump is transmitted from the boiler room to the engine room on the boiler-room telegraph. The main feed pump is kept warm, and, being turbo-driven, can be relied upon to start immediately the steam valve is opened.

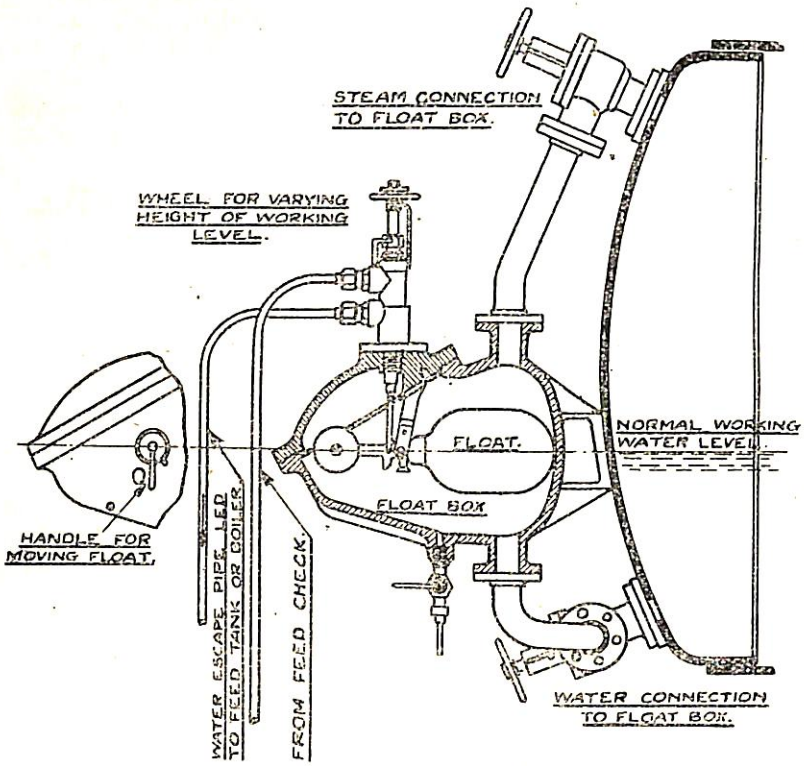
In a few ships with rotary main feed pumps, smaller pumps, known as *cruising feed pumps*, are provided for feeding the boilers when steaming at low power. Also a small feed pump, known as the *harbour service feed pump* is provided in some ships for use when in harbour, as it is uneconomical to use a large feed pump under these conditions.

29. Automatic Feed Regulators.—This regulator is fitted on the main feed supply, automatically to control the level of the water in the boiler. The spindle of the main feed check must be in the wide open position when feeding automatically. On no account must reliance be placed on the continuous correct working of the

automatic. Should the automatic prove unreliable, it can be put out of action by opening a small valve or cock and the feed controlled by hand. It has been found that if the automatic regulator fails suddenly when the valve is wide, or nearly wide, open, the water may rise above the top of the glass, before the main feed check can be closed the amount necessary to keep the water level steady. It is desirable, therefore, to be able to close the feed-regulating valve momentarily. In new ships a small valve is provided which, if opened, will cause the feed-regulating valve to close quickly.

When the automatic is operating, the feed supply is controlled by a float in a chamber attached to the steam drum. Figs. 9 and 12 show two typical arrangements. A pipe connects the top of this float chamber to the upper part of the steam drum, and another pipe connects the bottom of the chamber to the lower portion of the drum. A valve is fitted on each of these pipes, so that the chamber can be isolated from the drum if necessary. With these valves open, the level of water in the float chamber will be approxi-

FIG. 9. FLOAT CHAMBER OF MUMFORD & STEADYFLOW FEED REGULATOR.


STEAM CONNECTION TO FLOAT BOX.
WHEEL FOR VARYING HEIGHT OF WORKING LEVEL.
NORMAL WORKING WATER LEVEL.
FLOAT.
FLOAT BOX
HANDLE FOR MOVING FLOAT.
WATER ESCAPE PIPE LED TO FEED TANK OR BOILER.
FROM FEED CHECK.
WATER CONNECTION TO FLOAT BOX.

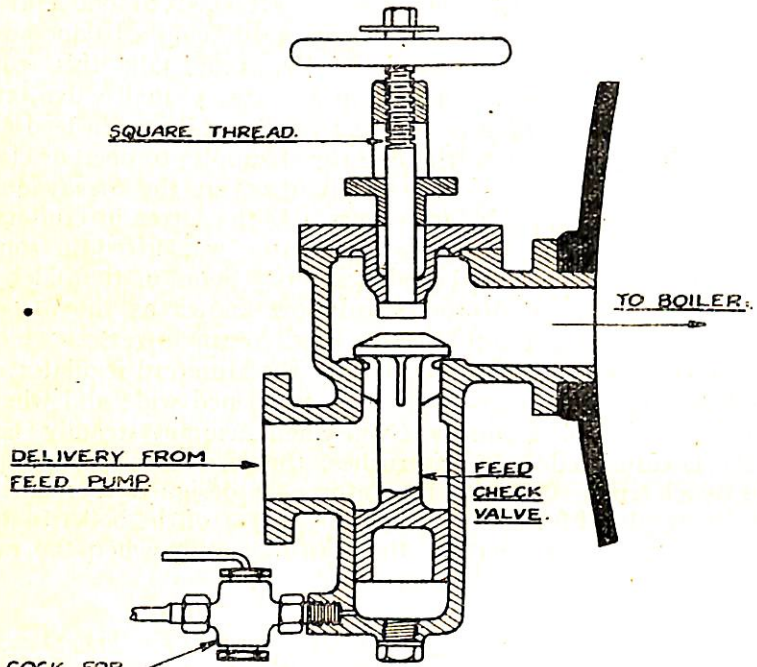
mately the same as the level of the water in the steam drum. (As the water in the boiler will contain bubbles of steam, it will take a slightly greater head of water in the drum to balance the head in the float chamber.) The float is attached to one end of a horizontal arm, pivoted in the centre, and having a balance weight at the other end. As the water level rises and falls, this arm will pivot about its fulcrum. This arm actuates a small valve, known as a needle valve, which in turn causes either the main feed check, or an additional valve on the main feed supply, to open or close.

The two regulators now generally fitted are the *Steadyflow* and the *Robot*, the former in destroyers and the latter in cruisers and larger vessels. The *Contraflow* regulator was fitted in some of the first ships with closed feed systems. Some of the older ships have an early form of the Steadyflow known as the *Mumford*, and this regulator is still being fitted in small vessels which do not have a closed feed system. With the Mumford regulator, when the float falls, the main feed check is opened wide and when the float rises, the check shuts. Even when steaming steadily the feed water is admitted in quick rushes, the feed check valve closing after each rush. Modern regulators are designed to maintain a steady supply of feed water when the output of the boiler is steady, and to increase or decrease the rate of supply when the rate of evaporation is increased or decreased.

30. The Mumford and Steadyflow Regulators.—The Steadyflow regulator was developed from the Mumford regulator and these two regulators are in many respects similar. Fig. 9 shows the arrangement of the float-controlled needle valve, while Figs. 10 and 11 show the feed check valves whose movement is controlled by the needle valve. Feed passes to the space under the piston attached to the feed check valve, either through a small clearance around the piston in the case of the Mumford, or through a port in the piston in the case of the Steadyflow. A pipe leads from this space to the needle valve. If the cock or small valve fitted on this pipe is closed, the feed pressure will lift the feed check, until the top of the valve comes against the bottom of the screwed spindle. Under these conditions the supply of feed water can be controlled by hand. Similarly, if the needle valve completely shuts off leakage from below the piston, the feed check will open to the full extent permitted by the spindle, and remain open as long as the needle is closed. This is the action that takes place in the Mumford Regulator.

In the Steadyflow the needle valve has a long tapered end which can reduce but never completely shut off the passage of water. Also the port in the piston of the feed check works over another tapered spindle. The area through which water can leak away from the

FIG. 10. "MUMFORD" FEED CHECK VALVE.



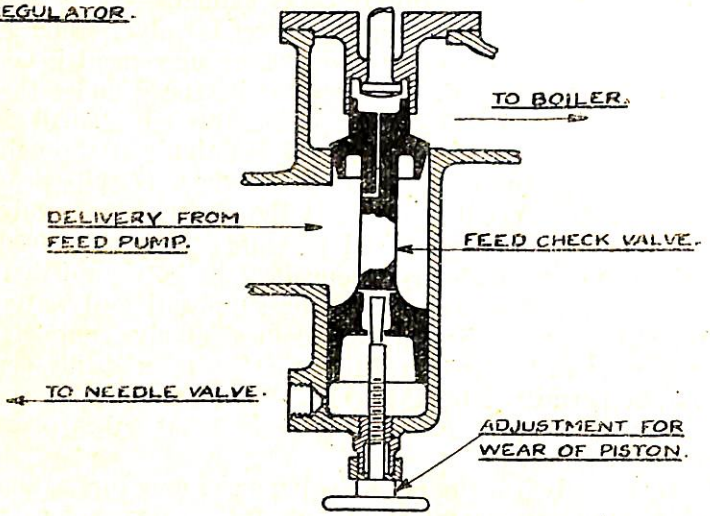


FIG. 11. "STEADYFLOW" FEED CHECK VALVE.

space below the piston will depend on the position of the needle valve, and the area through which feed water can flow into this space will depend on the position of the feed check. For any position of the needle valve the feed check will take up a definite position, such that the effective area of the port through the piston is just sufficient to maintain a pressure under the piston equal to the pressure on top of the feed-check valve. In other words, the feed-check valve will follow the movement of the needle valve, rising when the float falls and falling when the float rises.

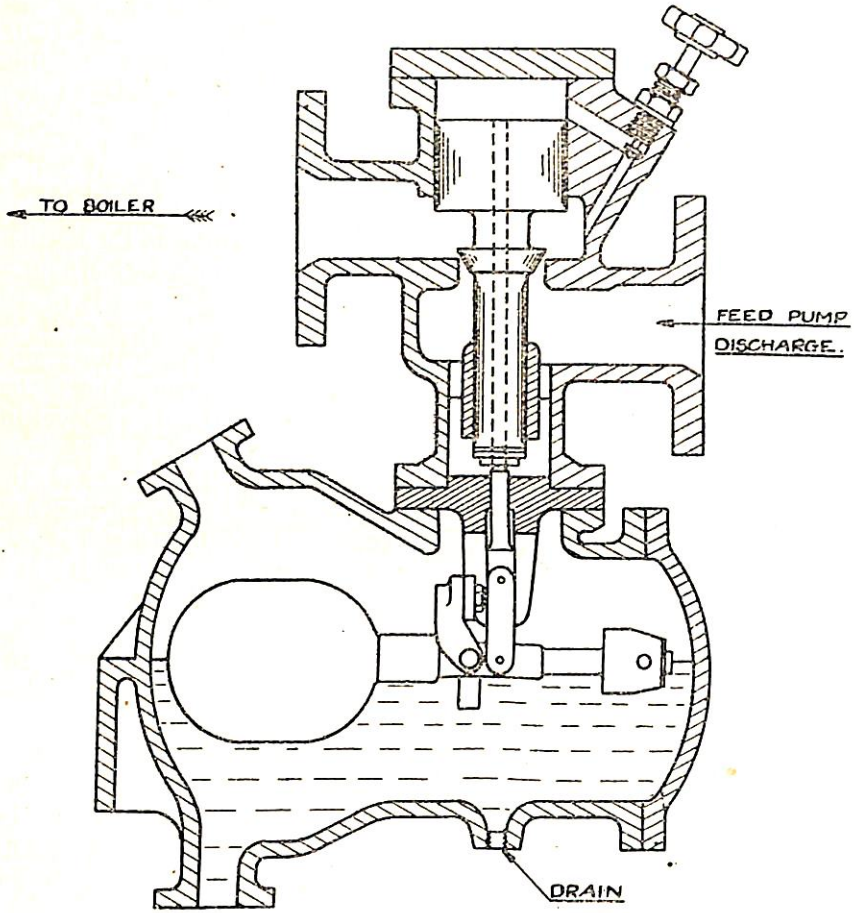
In both the Mumford and the Steadyflow regulators the needle-valve seat can be raised or lowered a small amount, by turning a handle on top of the needle-valve box. If the valve seat is raised the float will have to drop to bring the needle valve back to the same position relative to its seating, and the level of water maintained in the boiler will be lower. Similarly, screwing down the needle-valve seat will have the effect of raising the water level in the boiler.

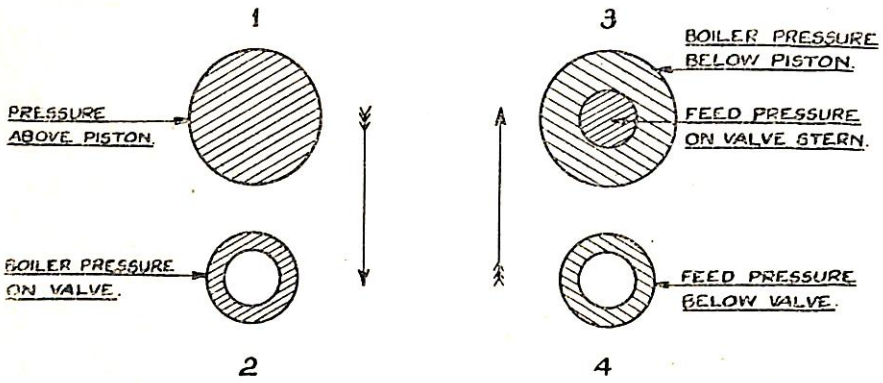
The method of changing from automatic to hand control, by shutting off a cock or leak from the space under the piston, has been mentioned. This fitting is common to all Mumford and Steadyflow automatics. In the new Steadyflow a second small valve allows of the pressure from under the piston being released to the bilge. This valve can be operated from the floor plates, and enables the feed check to be closed quickly if required.

In the Mumford and the early Steadyflow the pressure over the whole area of the top of the feed check is boiler pressure. The pressure below the piston will therefore be equal to boiler pressure in the early Steadyflow, and vary from feed pressure to something below boiler pressure in the Mumford. The leak off from the needle valve cannot be admitted to the boiler, and it is therefore led to the main feed tank. In the modern Steadyflow, illustrated in Fig. 11, the pressure on part of the top of the feed check is feed pressure, and on the remainder, boiler pressure. The pressure below the piston, with the feed check in the normal balanced position, will be greater than boiler pressure, and the leak off from the needle valve can be led to the boiler.

31. Robot Regulator.—Fig. 12 shows a section through this regulator. The drawing is not to scale. The feed-regulating valve is situated on top of the float chamber. It cannot be operated by hand, and a separate non-return feed check valve is fitted between the regulator and the boiler. Feed pump pressure is admitted to the space above the piston through the needle valve, and can leak away around the circumference of the piston to the boiler side of the regulator chamber. This regulator valve takes up a position relative to the needle valve, so that the pressure on the piston is

FIG. 12. "ROBOT" FEED REGULATOR.

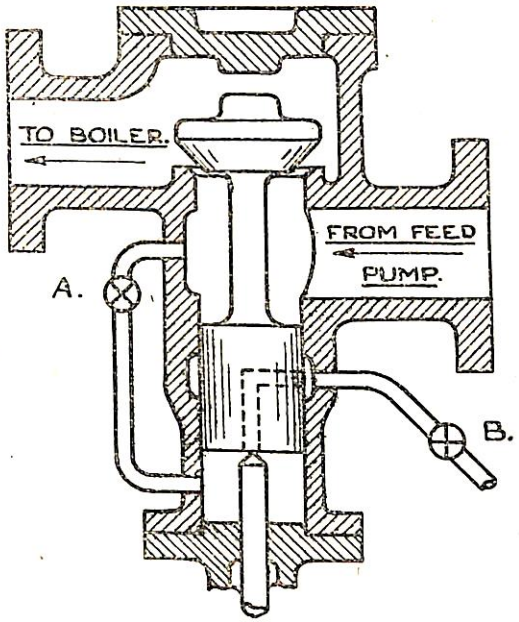




just sufficient to keep the valve balanced. Referring to the sketch showing pressures on the piston and valve, it will be seen that if 1 and 2 are to be equal to 3 and 4, then, as 4 is greater than 2, 1 must be greater than 3. In other words, the pressure above the piston, when the valve is balanced, will be some pressure between the feed pressure and the boiler pressure. A pressure gauge is fitted so that this pressure can be seen. If the needle valve rises, the pressure above the piston will be reduced, while if the needle valve drops, the pressure will be increased. In each case the regulating valve will follow the needle valve, thus restoring the condition of balance. A port connects the top and bottom of the piston, and a small valve is fitted in this port. If this valve is opened, the pressure above the piston cannot rise above boiler pressure. Referring to the diagram of pressures, it will be seen that under those conditions 3 will be greater than 1, and, as 4 is greater than 2, the regulating valve will move up to the full length of its travel. For hand feed this by-pass valve is opened, and the feed controlled by the main feed check. An extension spindle is generally fitted, so that this by-pass valve can be operated from the floor plates.

No external means are provided to alter the level of water maintained by the regulator. To do this the regulating valve must

FIG: 13.



CONTRAFLO FEED REGULATOR.

be taken out, and the thickness of washers under the needle-valve seating increased to raise the water level, or decreased to lower the level.

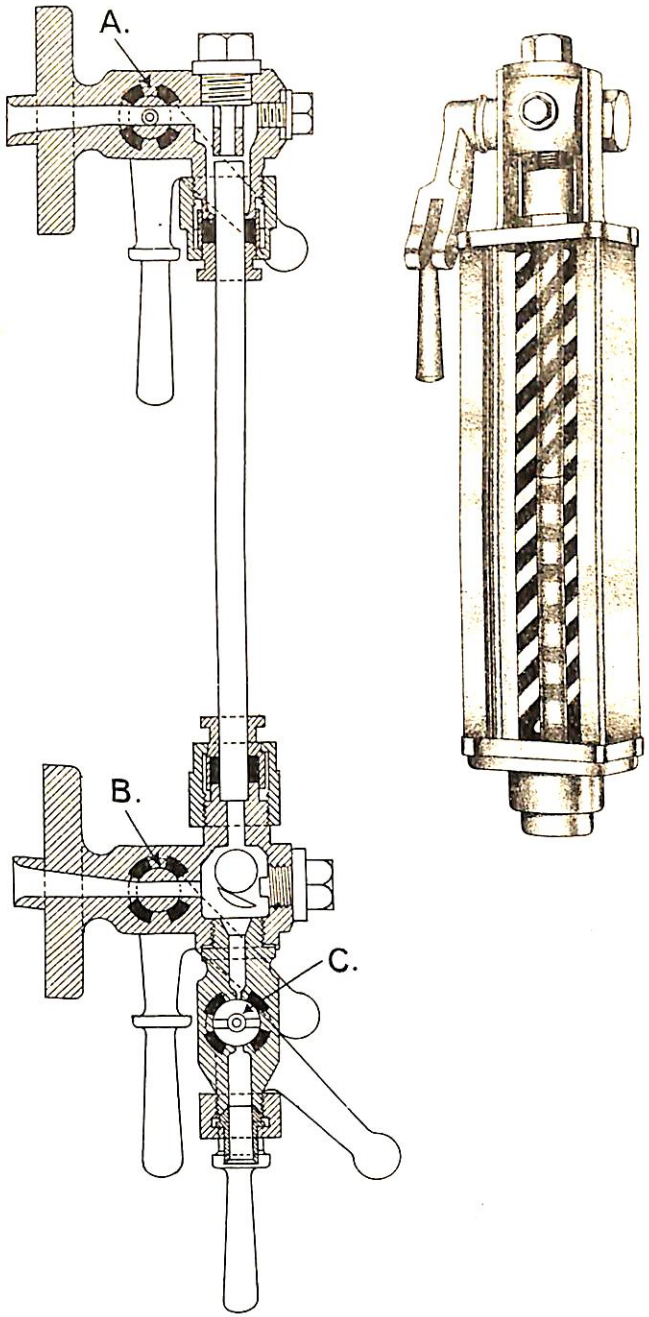
32. The Contraflow Regulator is illustrated in Fig. 13. As in the Robot, the feed-regulating valve is fitted on top of the float box. Feed water pressure is admitted to the space under the piston, through the valve A, and passes away to the main feed tank through the needle valve and valve B. The regulating valve takes up a position relative to the needle valve, so that the pressure in the space below the piston balances the boiler pressure on top of the valve. Valve B is closed for hand feed. A separate main-feed check may be fitted for hand control, or a screwed spindle may be fitted above the regulator valve. A slight variation of water level may be obtained by adjusting the amount of opening of valve A. Larger adjustments are made by washers under the needle-valve seat.

33. Water Gauges.—To show the level of water in a boiler two gauge glasses are fitted, so that about half a glass of water is shown when the water level is at the correct working height. The commonest form of water gauge is a glass tube, fitted between two mountings on the boiler, with a gland containing an asbestos and rubber ring at each end. Boilers sometimes have one tube glass and one *Dewrance & Wall water-level indicator.* The latter consists of a long gunmetal box with two plate-glass windows. The bottom of the box is jointed to the bottom gauge-glass mounting by means of a union nut and copper washer, while a tube from the top end of the box passes through the gland in the top mounting.

An electric light is fitted behind each water-gauge glass, in order that the height of water may readily be seen. Oil lamps are also fitted, in case the electric light should fail.

Fig. 14 shows on the left-hand side a section through the top and bottom gauge-glass mountings with a tube glass in position. Thick protector glasses are fitted in front and at the sides of the tube glasses, to prevent damage to watchkeepers from flying fragments, should a glass burst. These protector glasses are shown in position on the front view of the glass on the right-hand side of Fig. 14. This view also shows the effect of a plate with a number of diagonal slots, now generally fitted behind tube glasses. The diagonal beams of light from the slots are distorted only a slight amount on passing through that portion of a tube glass which is empty, while the beams that pass through the column of water are very considerably distorted. With this fitting no doubt will exist as to whether the glass is full or empty, in the case where the water level is not showing in the glass.

FIG. 14.



WATER GAUGE.

L. 693. 43777. D.6904. 45000. 4/41.

Malby & Sons, Lith.

The top and bottom gauge glass mountings are connected to the boiler by short lengths of pipe, known as *stand pipes*. The top mounting contains the steam cock A, and a plug on top with an extension piece to prevent the glass working up and the bottom end coming out of the lower packing ring. The bottom mounting contains the water cock B, and a ball to prevent the watchkeepers being scalded by the escape of boiling water should the glass break. Screwed into the bottom mounting is a drain cock C, from which a pipe is led to the bilge. A screwed plug in each mounting allows of the orifices being sighted through when the boilers are open for cleaning.

With the steam and water cocks open and the drain cock shut, the water level in the boiler, when at the correct height will show at, or just below, half way up the glass. The handles on the cocks are arranged so that when the cocks are in the working position, that is steam and water open and drain shut, the handles point downwards. This overcomes any tendency of the cocks to move from the working position due to the weight of the handles. Provision is made so that the cocks can be operated from the floor plates.

To replace a broken tube glass proceed as follows :—

(1) Having shut off the steam and water cocks and opened the drain, remove the protector glasses, the gland nuts, and the plug on top of the upper mounting.

(2) Fit new packing rings in both glands, and thread these and the union nuts over a new glass.

(3) Insert one end of the glass into the upper mounting, and raise it far enough to allow of the other end being entered into the lower mounting.

(4) Replace the top plug, and check that glass has not less than $\frac{1}{8}$ inch vertical freedom, to allow for expansion.

(5) Screw up gland nuts hand tight.

(6) Warm glass by opening steam cock slightly, keeping drain cock open.

(7) Tighten up gland nuts and replace protector glasses.

(8) Test gauge glass.

At the beginning of each watch and also after renewing a glass, each water gauge should be tested.

To test a boiler water gauge proceed as follows :—

(1) Shut the steam and water cocks and open the drain cock.

(2) Open steam cock slowly, and close it when steam is heard blowing from the drain pipe. This will show that the steam cock is clear.

(3) Open water cock slowly. If the water orifice is clear, the water as it issues from drain cock will boil, due to the

reduction in pressure. When steam and water are heard blowing from the drain pipe close water cock.

(4) Having ascertained that steam and water orifices are both clear, close drain cock.

(5) Watching the glass, open the water cock slowly. Water should be seen entering the glass. The water level will rise to the top of the glass, due to the pressure in the boiler. If water does not appear in the glass, the water level in the boiler must be below the bottom orifice.

(6) If water has appeared in the glass, while still watching the glass, open the steam cock slowly. The level of the water in the glass will now fall to the level of the water in the boiler. If the water level does not appear in the glass the boiler is too full.

The level of water in a boiler should always be kept at such a height that it can be seen in the gauge glasses. If the water level rises above the top of the glass priming may take place, and the machinery may be damaged. If the water level falls below the bottom of the glass, the boiler may in a few moments become so short of water that tubes will become overheated. Where the complement permits, a petty officer or leading stoker is detailed as water tender in each boiler room, and this man's only duty is to regulate the level of water in the boilers. The detailing of a water tender does not relieve the Chief Stoker or Petty Officer in charge of the boiler room of his responsibility that the correct water level is maintained.

When extra sprayers are put on, the increase in the quantity of bubbles of steam causes an increase in the volume of water in the boiler, and the water level rises. Sprayers should not be put on so rapidly, that the water level rises above the top of the glass.

When easing down there is a reduction in the quantity of steam bubbles, and hence a reduction in the volume of water. The water level will fall, and may disappear out of the glass, if it is necessary to shut off a large number of sprayers at once.

A failure of the automatic feed regulator, may cause the water level to rise above the top of the glass, or to fall below the bottom. The pressure in the leak off chamber will indicate whether the automatic is functioning correctly. Water tenders should make themselves familiar with the reading of the leak off pressure gauge, when the type of automatic fitted is working correctly. If the automatic fails, the main feed check must be changed over to hand control, and the auxiliary feed pump and auxiliary feed check brought into use if necessary. If it should be necessary to control the supply of feed water to a water-tube boiler by hand when steaming at high powers, a responsible rating must be detailed for the sole duty of water tending this boiler. Auxiliary feed check

valves should be tried occasionally to ensure that they are free, and auxiliary feed pumps kept ready for instant use.

If the water level rises above the top of the glass the main feed check must be shut, until the correct water level is restored and the engine room informed that priming may occur. The water level can be brought back into the glass quickly, by blowing some of the water from the boiler overboard through the blow-down cocks. In boilers fitted with superheater, priming will be indicated by a large drop in the temperature of the superheated steam. If priming should occur the supply of fuel must be reduced. If necessary shut off the fuel supply entirely, and close main and auxiliary stop valves.

A drop in the water level may be due to a failure of the main feed pump. This will be shown by the feed discharge pressure gauge in the boiler room. The auxiliary feed pump must be at once brought into use, and the engine room informed. It is better to pass the discharge from the auxiliary feed pump through the feed heater, but the supply of cold feed water must be accepted if it is the quicker operation. The procedure in the event of having to bring the auxiliary feed pump into use must depend on the arrangements in the ship, and should be as ordered by the Engineer Officer. All boiler-room watchkeepers must be familiar with these orders. Should the auxiliary feed pump be in use for feeding a boiler, the boiler-room watchkeeper must understand clearly what alternative means of feeding the boiler are available, and how this can be brought into immediate use.

Should the water level fall below the bottom of the glass, where this is not due to sprayers becoming shut off too quickly, the rate of burning of fuel must be reduced and every possible means adopted to increase the rate of feed supply. If the water level is below the bottom of the glass but still above the bottom orifice, closing the steam cock of the water gauge will cause the glass to fill with water. If no water appears on closing the steam cock, shut off all fuel supply, close main and auxiliary stop valves, and inform the Engineer Officer of Watch or Day.

34. Cocks.—For certain purposes cocks are used instead of valves. A cock consists of a casting, known as the shell, in which is fitted a plug having a passage through it.

The top of the plug should be marked, to indicate what type of passage (straight through, right angle, etc.) exists in the plug, so that at a glance it can be seen whether a cock is open or shut. Generally on a straight-through cock, the handle is fitted in line with the passage in the plug.

Ratings should draw the attention of their officer to any

unmarked plugs, so that grooves can be placed on them at the first convenient opportunity.

35. Air Cocks.—When a boiler is to be filled with water, mean must be provided for the air in the boiler to escape. Similarly, if it is desired to empty a boiler, it is necessary to allow air to enter the boiler. Consequently, cocks are fitted at the highest points of the boiler, one at each end of the steam drum, and one on each superheater drum if fitted.

When a boiler is quite full of water it is said to be at WW, and when it is only filled to working height it is said to be at W. Boilers are normally kept completely filled with water, so as to exclude any air, but before steam is raised in a boiler, water is run out of it, usually into the reserve feed tanks, until the water level is at working height.

When raising steam, the air cocks are kept open until steam issues from them, and then they are shut off. This procedure is important when raising steam in boilers which are to be connected to others already in use.

36. Hydrometer Cock.—This cock, fitted to some convenient position on the boiler, is for drawing off water for testing. If no hydrometer cock is fitted, water can be drawn off through the gauge-glass cocks.

37. Blow-down Cocks.—These cocks, fitted at the bottom of the boiler, are used for blowing out dirty water to the sea when the boiler is under steam. They are connected by a pipe or hose to a valve on the bottom of the ship.

In larger ships the blow-down cocks are fitted in pairs, one pair on each water drum. The upper cock must be opened before the lower cock, and when shutting off the lower cock should be closed first. By this means the upper cock does not suffer from the scoring action of the water and dirt passing through it when partially open. In older ships there is usually an additional cock between the cocks on the boiler and the sea cock. The handles of blow-down cocks are portable, and are fitted with a feather, so that they cannot be removed unless the cock is closed.

38. Running-down Valve.—By means of this valve a boiler can be run down to the required working level for lighting up, or to empty for cleaning. The water can generally be run by gravity through a hose to the reserve feed tanks. If the reserve feed tank is too high the water must be pumped out with the auxiliary feed pump. Filters are generally provided, through which the water can be passed before going to the feed tank. If the water is excessively dirty, or contaminated with sea water, it is run to the bilge.

In destroyers a valve on each water drum acts as a running-down or blow-down valve. A hose from this valve can be connected either to the sea cock or the reserve feed tank.

39. Superheater Drains.—When superheaters are fitted, it is necessary that these should be kept drained when the boiler is steaming. A drain valve is fitted on each superheater drum, the drain being led through a steam trap, to the reserve or overflow feed tanks. These drain valves also act as running-down valves for emptying the superheaters of a boiler at WW, when it is to be lit up, or opened for cleaning.

40. Pressure Gauges.—Two pressure gauges are fitted to each boiler, one of which reads to a few pounds over the working pressure, and the other to about double the working pressure. The two gauges form a check on each other. A cock is fitted where the pipe for the gauge joins the boiler, and another cock at the gauge. When a boiler is tested to test pressure, the gauge with the lower scale is shut off.

41. Distant Reading Thermometers.—On modern boilers two of these thermometers are fitted to record on dials on the boiler front—(1) the temperature of the steam leaving the superheaters, (2) the temperature of the flue gases leaving the air preheaters.

42. Soot Blowers.—These are fitted on modern water-tube boilers, so that soot, which collects on the outside of the tubes and in the air preheaters, can be blown up the funnel, while the boilers are in use. A valve, on the boiler side of the main stop valve, supplies steam to nozzles, fitted on the front and back of the furnace and below the air preheaters. There is also a separate steam valve at each nozzle. The jet or jets of steam issuing from a nozzle are directed into the tubes by revolving the nozzle. The furnace ends of the nozzle are protected as far as possible by brickwork. In some boilers the nozzles on the furnace side of the tubes can be drawn back a few inches when not in use. Soot blowers should be used only when orders are received from the Engineer Officer of the Watch or Day.

CHAPTER IV.

FUELS, ARRANGEMENTS FOR BURNING, MANAGEMENT OF BOILERS.

43. Fuel—General.—In the early days of the history of the world, conditions were favourable to the rapid growth of vegetable life. In many parts of the world large deposits of decaying vegetable matter and marine organisms accumulated, and were covered over with layers of sand, clay, etc. Such deposits have gradually been converted into coal or petroleum, and form the source from whch we obtain our fuels.

Petroleum is a mixture of a very large number of compounds of carbon and hydrogen, with traces of other substances. From petroleum we obtain, by distillation, petrol, paraffin, diesel oil, lubricating oil, and boiler oil.

Coal consists of carbon, with a varying quantity of hydrocarbon compounds, and some incombustible matter. If coal is heated, most of the hydrocarbons pass off in the form of gases. Most of the gases obtained by the distillation of coal are used as coal gas, but a small quantity can be condensed to form liquid fuels. The remains, when all the volatile matter has been distilled off, is known as coke.

Either oil fuel or coal may be used in a boiler for the production of steam, or both fuels may be used at the same time, if the furnaces in which they are to be burned are suitably constructed.

There are very extensive deposits of coal in Great Britain, but practically no petroleum. Coal is therefore cheaper in this country than oil fuel, practically all of which has to be imported. For use on board ship oil fuel has so many advantages over coal, that practically all our warships and larger merchant vessels now burn oil only. The heating value of oil fuel is about 40 per cent. greater than that of coal, more oil can be burnt in the same size furnace, and the transport of oil into the ship, and thence to the furnace, is much simpler. A coal-burning warship would require more boilers for the same speed, and full speed could not be so quickly obtained, or kept up for so long. Re-fuelling would have to take place more frequently, it would take longer and necessitate the employment of the whole ship's company, who in wartime would have long hours on duty at sea, and be in need of rest when in harbour.

44. Combustion.—If raised to a sufficiently high temperature, both carbon and hydrogen will combine with oxygen, and in each

case the combination gives rise to a large quantity of heat. This chemical change is known as combustion or burning.

By the combustion of the hydrogen in a fuel water vapour is formed. There are two compounds of carbon and oxygen, known as carbon dioxide or CO_2, and carbon monoxide or CO. Both of these compounds are gases at normal temperature and pressure. When carbon is burnt to form carbon dioxide, more oxygen is used and more heat is evolved than when it is burnt to carbon monoxide. The full heating value of a fuel will not have been obtained if there is any CO present in the final products of combustion. If there is insufficient oxygen present for the complete combustion of a hydrocarbon fuel, or if the burning gases be suddenly cooled before combustion is completed, small particles of carbon will remain unburnt, and give rise to smoke.

Air consists of about one part of oxygen to four parts of nitrogen. When a fuel is burnt in air, the nitrogen remains unchanged except that its temperature is raised.

The temperature obtained by the combustion of coal or oil in a furnace will be in the region of 3,000° F. At this high temperature the gases formed are incandescent and radiate heat to the walls of the furnace. In a water-tube boiler some of this radiant heat falls directly onto the firerow tubes, while the remainder falls on the brickwork. The surface of the bricks becomes red hot, and also radiates heat to the tubes. The hot gases, as they pass around the tubes to the uptakes, are brought into contact with the metal surfaces, and a further quantity of heat thus passes to the tubes. When the gases leave the last row of tubes, their temperature will have been reduced to about 600° F. On appreciable quantity of the heat of combustion is thus lost up the funnel. Any air admitted to the furnace, beyond that necessary for the complete combustion of the fuel, will, increase the loss of heat in the funnel gases.

45. Air Supply—Natural and Forced Draught.—The supply of air to the furnace may be by *natural draught*, that is the draught due to the chimney or funnel. In ships the natural draught is limited by the fact that the funnel cannot be more than a certain height. Forced draught fans must therefore be used to increase the quantity of air flowing into the furnace.

Two systems of *forced draught* are used, known as the open stokehold and the closed stokehold. In the open stokehold the fan supplies the air through a trunk to the furnace front. This fan may take its suction from the boiler room or from the upper deck, but in either case the stokehold is open to the air outside. This system is often referred to as the Howden system. In the closed stokehold system an air pressure is maintained in the boiler room by fans, which draw air from the upper deck. Air from the boiler

room enters the furnace through draught plates and air flaps, which are so arranged that they will close automatically, if the bursting of a boiler tube should cause the pressure in the furnace to exceed the pressure in the boiler room. Attention should be paid to automatic doors to ensure that they work freely and that no restriction prevents their closing under the influence of a back draught. Air locks are provided, to allow access to and from the boiler room without loss of air pressure. The air pressure in the boiler room is recorded by an *air-pressure gauge*. This is a glass U-tube with a little coloured water at the bottom. One end of this tube is open to the boiler room, and a pipe from the other end leads to the outside air. The difference in the height of the water in each leg of the U-tube can be read off on a scale in inches.

46. Forced Draught Fans.—These are generally turbine driven. To ensure that all the fans should be run at the same speed, and so give a uniform supply of air, the steam supply to all fans in the stokehold is controlled by one master steam valve. An additional steam valve is fitted at each fan; this valve should be wide open when the fan is in use. Turbine-driven fans have an *overload valve*, which must be opened if it is required to run the fan at full speed. In modern ships, this overload valve can be opened from the stokehold floor plates. Turbo fans also have an *overspeed governor*, to shut off the steam supply should the revolutions of the fan exceed those for which it was designed.

A diaphragm shutter is fitted on the air supply to each fan. In the latest ships it is arranged that the shutter closes automatically if a fan stops. This prevents a complete loss of air pressure in a boiler room if the overspeed governor of one fan trips.

47. Coal.—Coals are classified according to the amount of volatile matter they contain. Bituminous coals contain 20 to 30 per cent. of volatile matter, while anthracite contains only about 5 per cent. Certain coals are found in the Welsh coalfields which contain about 15 per cent. of volatile matter. These coals, known as semi-bituminous or Welsh steaming coals, give the best results in ships' boilers.

48. Combustion of Coal.—The coal can be burnt in the furnace, either on a grate or as pulverised fuel, *i.e.*, by grinding it into powder and blowing this powder into the furnace in a stream of air, the mixture of air and coal dust being ignited as it enters the furnace. With the pulverised-fuel system coals can be used which are not suitable for burning on a grate. It has not been adopted for warships, on account of the weight of the machinery necessary to grind the coal.

Coal can be fired onto a grate either mechanically or by hand.

Mechanical stokers are extensively employed for large shore boilers and are used in a few merchant ships. Marine boilers are usually fired by hand. For good results it is essential that the coal be spread evenly over the grate, and that only a few shovelsful be put on at a time. The volatile content of the coal is distilled off as gas when the coal is thrown on to the fire. If too much coal is put on at a time, so much gas will be formed that the supply of air will temporarily be insufficient to ensure complete combustion. Any gas from the coal which is not consumed in the furnace may burn on meeting a further supply of air at the top of the funnel.

The major portion of the air required for the combustion of the coal is admitted to the space below the grate. Draught plates are fitted so that the quantity of air admitted, and hence the rate at which the coal is burnt, can be controlled. In some boilers provision is also made to admit some air above the grate, when burning bituminous coals.

Some of the incombustible content of the coal falls through the firebars which form the grate, but a certain quantity fuses on the grate and forms clinker. This clinker must be removed periodically as otherwise it would prevent the passage of air through the grate. The ashes and clinker removed from the furnace are either hoisted up an ash hoist to the upper deck and thrown overboard, or expelled through the side of the ship by means of an ash ejector.

49. Lighting up a Coal-fired Boiler.—The boiler is first primed and topped. The priming is a layer of small coal, about 4 inches thick, spread evenly over the grate. The topping is a wall of lumps of coal built over some pieces of wood just inside the furnace door. This wall should be about 2 feet thick at the bottom, and should be built as close to, and as much above, the open furnace door as possible. Priming and topping is usually done the day before the boiler is to be lit up.

To light up, the furnace doors are propped open, and the wood under the topping is ignited by means of a piece of oily waste. When the topping is well burnt through, it is spread over the grate. With water-tube boilers a small amount of water is run into the ash pans. The furnace doors are closed, and the draught plates opened until the priming is well alight. The draught plates are then adjusted so as to raise steam slowly.

With a water-tube boiler steam can be raised to working pressure in from two to three hours from the time of lighting up. With a cylindrical boiler there is a danger of causing joints to leak if steam is raised quickly. The centre furnace should be lit up three or four hours before the wing furnaces, and eight to twelve hours taken to raise steam.

50. Steaming Coal-fired Boilers.—Coal is obtained from the

bunkers in skids, and the number of skids of coal used each hour should be reported to the engine room for recording in the engine room register. This tallying must be done carefully, so that the amount of coal used can be estimated accurately. Any foreign substance found in the coal should not be put into the furnace, unless it is known that the nature of the substance is such that no harm will result to the boiler.

To ensure economical working and to maintain a steady steam pressure it is necessary to keep the fires level, of correct thickness, and to fire up regularly. Under conditions of natural draught a fire of about 4 to 6 inches thick gives the best result, but when forced draught is used and the boilers are being steamed at their maximum output the fires will probably have to be thickened.

The coal used must be well broken up, the largest lump not larger than a man's two fists placed together, and firing must be done quickly.

When a furnace door is open for firing, the stoker should see at a glance where the fire is getting thin and coal is required. The places towards the back of the boiler should be dealt with first, as if the thin places at the front of the furnace are fired up first, the flame so caused prevents the stroker from subsequently seeing the thin places towards the back of the boiler.

Care must be taken to prevent the fires from becoming thin at the sides of the grate and between the furnace doors, and fires must be kept clear of the furnace doors, which otherwise would be burned and distorted.

51. Cleaning Coal Fires.—The routine of cleaning fires, by which is meant the complete removal of the fire opposite a furnace door and its replacement by new and unburned coal, is generally commenced about twelve hours after leaving harbour. Usually one fire in each boiler is cleaned in each four-hour watch. This is necessary, as after steaming for some time, the fires become clogged with clinker and dirt, and consequently the fresh fuel added is not burned efficiently, and further, the output of steam from the boiler is so reduced that it may not be possible to maintain the speed ordered.

Before a fire is cleaned it is burned down, that is to say no more coal is put upon it, and the fire in the adjoining furnace is thickened up instead. When the fire to be cleaned is nearly dead, any clinkers which are sticking to the firebars are freed from them by using a slice (care being taken not to knock down the brickwork), and then the whole fire is withdrawn by means of a rake. As the fire is withdrawn, it is cooled down by a second stoker with a hose (this stoker also holds the furnace door open).

As soon as the fire has been withdrawn the grate is covered as

quickly as possible with new coal, to a depth of about 4 inches, and then, by means of the rake, part of the burning fire in the adjoining grate is drawn over on to the new coal to ignite it.

In cylindrical boilers, where each furnace door has a separate grate, after placing the fresh coal in the furnace that has been cleaned, a few shovelsful of burning coal are taken from the other furnaces to ignite the new fire. It is important that the cleaning of fires should be done as quickly as possible and not more than one fire should be cleaned at a time.

52. Oil Fuel.—Practically all boiler oils are the residue of petroleum after the more volatile fraction has beeen distilled off for sale as petrol, paraffin, and diesel fuel. For use as boiler oil the residue must be fluid enough to be pumped, it must be free ffom water and solid impurities, and contain not more than about 2½ per cent. of sulphur. Also its flash point, *i.e.*, the temperature at which it gives off vapour in sufficient quantity to form an explosive mixture with air, must not be less than 175° F. The limitation of the flash point is purely a safeguard against fire risks. For merchant ships fuel oils with a flash point down to 150° F. are accepted.

53. Combustion of Oil Fuel.—For burning efficiently without smoke, the oil must be broken up into a fine spray, and this spray must be mixed with the air required for combustion. The spray is formed by pumping the oil under pressure through sprayers on the front of the furnace, air being admitted around each sprayer. Boiler oils are normally so viscous that they cannot be broken up into a fine spray when cold. Oils become more fluid when heated, and by raising the temperature to between 100° and 200° F. the oil can be made as fluid as water. The temperature to which an oil should be raised depends on its viscosity. The best burning temperature for the oils normally supplied are given in the Engineering Manual. With the large output sprayers fitted in some of the latest ships, very high air velocities are required to get the necessary quantity of air into the furnace. Under these conditions good mixing of the fuel with the air may not be obtained if the spray is fine. An oil temperature lower than that recommended for general use is found to give better results.

54. Number and Output of Sprayers.—From one to twelve sprayers are fitted on each boiler, the number depending on the size of the boiler. A separate control valve is fitted to each sprayer. The sprayer control valves are numbered, so that it can readily be seen which valve controls which sprayer. The numbering is arranged so that No. 1 sprayer is the one that should be put on first, then No. 2, and so on. The steam pressure in the boiler is controlled by putting on or shutting off sprayers. In general,

sprayers of large output are fitted on large boilers, and smaller output sprayers on small boilers. All the sprayers on any one boiler are of the same output, except that one or two small output sprayers may be temporarily fitted on a large boiler to give better control of the steam pressure, when a relatively small quantity of steam is required in harbour. A sprayer with an output of about 250 lb. per hour is used for lighting up a cold boiler. (*See* Articles 62 and 66.)

55. Oil-Fuel System.—The essential fittings of the oil-fuel system are as follows: Suction valve on the oil-fuel tank, suction strainer, oil-fuel pump, filters, heater, emergency valve, thermometer, sprayer control valves, sprayers, combustion tube, and arrangements for lighting up from cold. Where oil-fuel pipes, etc., not in use, are exposed to the possibility of a rise in temperature, valves should be opened as necessary to prevent undue pressure due to the expansion of the oil. Pressure gauges fitted on the oil-fuel system should be left uncovered, so that any pressure may be observed.

56. Oil-Fuel Suction Valves.—The arrangements for the stowage of oil fuel in the various classes of ships are dealt with in a later chapter. Each oil-fuel tank has a suction valve, and where the tank to be used is not situated adjacent to the boiler room, there will be additional valves to be opened where the oil-fuel suction pipe passes through water-tight bulkheads.

57. Oil-Fuel Suction Strainers.—Coarse strainers are fitted in the suction pipe, to prevent any foreign substance accidently left in the tank reaching the pump. These strainers are fitted in pairs, so that one can be cleaned while the other is in use.

58. Oil-Fuel Pump.—These pumps must be capable of maintaining a steady pressure of from 25 to 150 lb. per square inch at the sprayers. There may be a separate pump for each boiler, but more usually one pump supplies two or more boilers in cruisers and larger vessels. Additional pumps are provided as stand-by, in case a pump breaks down. It has not been the practice to fit stand-by pumps in destroyers, but cross connections are fitted so that an oil-fuel pump in another boiler room can be used if necessary. In some of the latest destroyers, however, stand-by oil-fuel pumps are fitted. Each pump is fitted with a suction and discharge valve. The pumps are generally of the double-acting reciprocating type, but some of the later ships have turbo pumps.

Reciprocating pumps have a large air vessel, to ensure a continuous flow without pulsation. A gauge glass is fitted on the air vessel to show the level of the oil. Extra air can be admitted through a snifting valve on the suction side of the pump, and excess air can be released through the gauge glass drain cock, the

lower cock to the gauge glass being closed. On the discharge side of the pump is an adjustable spring-loaded relief valve, which can be set to lift at any desired pressure between 25 and 150 lb. per square inch, the surplus oil returning to the pump suction.

With *turbo pumps*, instead of a spring-loaded relief valve, a constant-pressure governor is fitted. This governor controls the speed of the pump, and it can be set to maintain any desired discharge pressure between 25 and 150 lb. per square inch. An emergency governor is also fitted to shut off the steam if the speed exceeds the maximum revolutions for which the pump is designed.

A combined pressure and vacuum gauge is fitted on the suction side of the pump. Should the pump run away, an appreciable vacuum on the suction side will indicate a choked suction strainer. If no vacuum is showing, the racing of the pump is probably due to the tank being empty.

59. Oil-Fuel Filters.—To prevent any dirt in the oil, which might have passed through the suction strainers, choking the sprayers, the oil is filtered on the discharge side of the fuel pumps. In older ships the oil is filtered both before it goes to the heater and after it leaves the heater. These filters are known respectively as cold and hot filters. The hot filters were fitted to intercept any particles of carbon which might be formed due to overheating of the oil. They have been found to be unnecessary and are not fitted in new ships.

Auto Klean filters are fitted in all ships built since 1928. The oil is filtered by passing it from the outside to the inside of a cylinder, built of a large number of steel discs spaced a few thousandths of an inch apart. This cylinder can be turned in its case, and when this is done, scrapers remove the dirt from between the discs. The dirt falls to the bottom of the case, and a door is provided so that the dirt can be removed periodically when the filter is not in use.

In ships built before the Auto Klean filter was adopted, *wire-gauze filters* were fitted. To clean these filters the perforated cylinders around which the gauze is wrapped have to be removed. The filters were therefore fitted in pairs, with the necessary valves to enable one to be shut off while the other is in use. In order that there shall always be a clean filter available, only one of each pair should be in use at a time. Pressure gauges on the inlet and outlet indicate when the filter requires cleaning.

60. Oil-Fuel Heater.—The heater consists of a nest of steel tubes encased in a steel shell. The oil passes through the tubes, and the outside of the tubes is surrounded by steam. Steam is admitted to the top of the shell, and a gauge shows the pressure in the shell. Three drains are fitted, one at the bottom and the others some distance up the heater. If the bottom drain is open, the whole

of the heating surface is in use. By keeping the bottom drain closed and using the centre or top drain, the lower portion of the heater remains full of water, and the heating surface is reduced. The temperature to which the oil is heated as it passes through the heater depends on which drain is used, and on the steam pressure in the shell. It is desirable that the steam pressure should be slightly higher than the oil pressure, so that in the event of a tube leaking oil will not pass into the drain water, and thence to the feed tanks. As a further precaution the drain water is led to an *observation tank* with a gauge glass, in which any oil floating on the water should be seen. The observation tank drains through a two-way cock, either to the reserve feed tank or to the bilge. The drain should be kept on the bilge when the heater is not in use, and should not be put to the feed tank until it has been proved that the water is free of oil. Any sign of oil in the drain water must be reported. A thermometer is fitted on each boiler, to show the temperature of the oil passing to the sprayers. Steam must not be put on the heater until the system has been opened out, and the heater should be warmed through gradually. If care is not taken, the oil may be overheated before circulation is started.

61. Oil-Fuel Emergency Valves.—A shut-off valve, which can be worked from a convenient position outside the boiler room, is fitted between the heater and the boiler. Arrangements are also provided to stop the oil-fuel pump from outside the compartment, by shutting the master steam valve, or by breaking the electric circuit in the case of motor-driven pumps. All engine room ratings should be familiar with these emergency arrangements, so that, in the event of a serious fire or other emergency, the oil-fuel system can be quickly shut off.

62. Oil-Fuel Sprayer.—There are two different Admiralty pattern sprayers in use, known as the old pattern and the new pattern. The principle is the same in each case, but in the new pattern sprayer certain improvements have been made, to obtain a finer spray, and to simplify the exchange of a dirty sprayer by a clean one.

Fig. 15 is an enlarged view of the outlet and of the *old pattern sprayer*. The portion of the sprayer containing the exit hole is known as the sprayer cap, and is made of tool steel. The oil enters the sprayer body through a screwed connection and passes along an annular space to the outside of the cap. It then passes to the cylindrical chamber in the centre of the cap through one or more tangential holes. The oil is thus caused to whirl round this chamber. Due to this whirling motion, the oil does not pass on through the exit hole as a solid jet, but as a hollow film of oil whirling round the surface of the exit hole, as it moves towards the outlet edge.

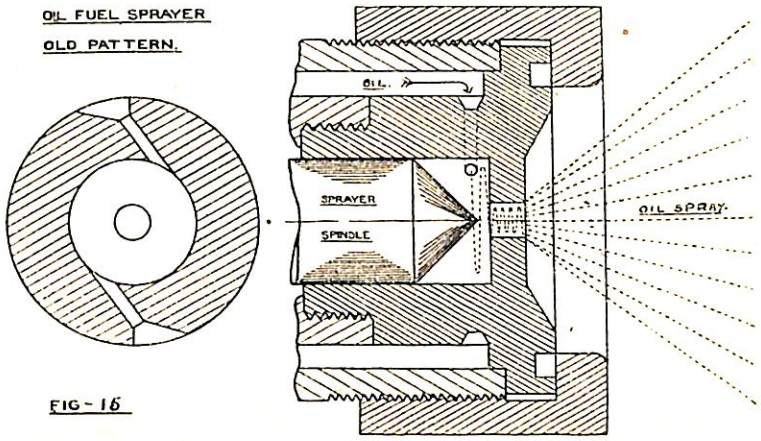


FIG - 16

At the outlet edge of the exit hole this hollow cylinder of oil, being no longer restricted by the surface of the hole, breaks up to form a hollow cone of spray. Any dirt in this exit hole will impede the rotation of the film of oil as it passes through, and cause a defective spray. It is also essential that the edges of the exit hole shall be sharp, and great care is necessary, when cleaning the sprayer, that these edges are not damaged.

The sprayer spindle has a screw thread in the centre, and by means of a handwheel at the end it can be moved, so that the conical end is nearer to, or further from, the exit hole. A collar on the spindle prevents the conical end actually touching the edge of the exit hole. This movement of the spindle affects the output of the sprayer and also the angle of the spray. It is not used to shut off the sprayer, for which purpose a special control valve is provided. An indicator is provided on the handwheel to show the position of the sprayer spindle. It has become common practice always to work with the spindle screwed out $1\frac{1}{4}$ turns from the hard in or shut position. The increase in output, by opening out the two turns, only amounts to about 2 per cent. The sprayer is bolted on to a bracket on the boiler front. Elongated holes allow of the sprayer being adjusted as necessary.

Fig. 16 is an outside view of a *new pattern sprayer*. The screwed spindle for adjusting the angle of spray is not fitted. The sprayer body fits in a carriage, in which it is secured by two hinged clips with butterfly nuts. The carriage is rigidly attached to the boiler front, and if it has been correctly lined up it is impossible to replace a sprayer out of line after cleaning. By means of a hand-wheel, the sprayer can be moved axially on its carriage. The adjustment of the sprayer to give the best results is dealt with in the next article.

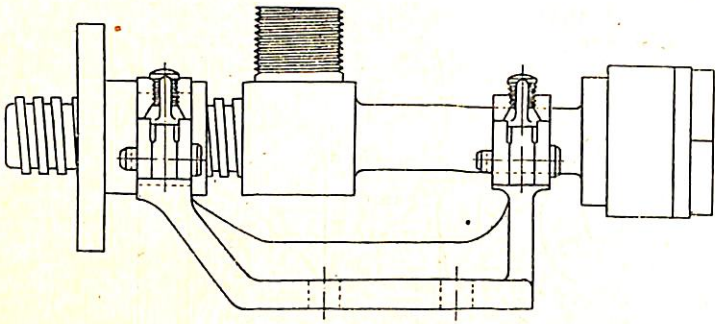


FIG - 16.

The output of a sprayer depends on the size of the outlet hole in the cap, and also to a lesser extent on the oil fuel pressure. Sprayer caps are made with different size exit holes for both the old pattern and new pattern sprayers. The sprayer caps are interchangeable for the same pattern sprayer, and the output at a pressure of 150 lb. per square inch is stamped on them.

63. Combustion Tube.—The oil spray is raised to the ignition temperature by directing the oil spray through a steel tube known as the combustion tube. If other sprayers are not already alight in the furnace, combustion is started by placing a piece of burning oily waste, or holding a torch, in the combustion tube. Once the spray is alight the combustion tube will be maintained at a sufficient temperature to ensure ignition. The combustion tube and the sprayer are so arranged that the oil spray is directed on to the inside surface of the combustion tube. The temperature of the combustion tube can be controlled by altering the position of the sprayer, withdrawing the sprayer further from the tube will keep the tube at higher temperature. The combustion tube must be maintained at a sufficiently high temperature to vaporise and ignite the oil directed on to it, but if it is too hot it will be burnt.

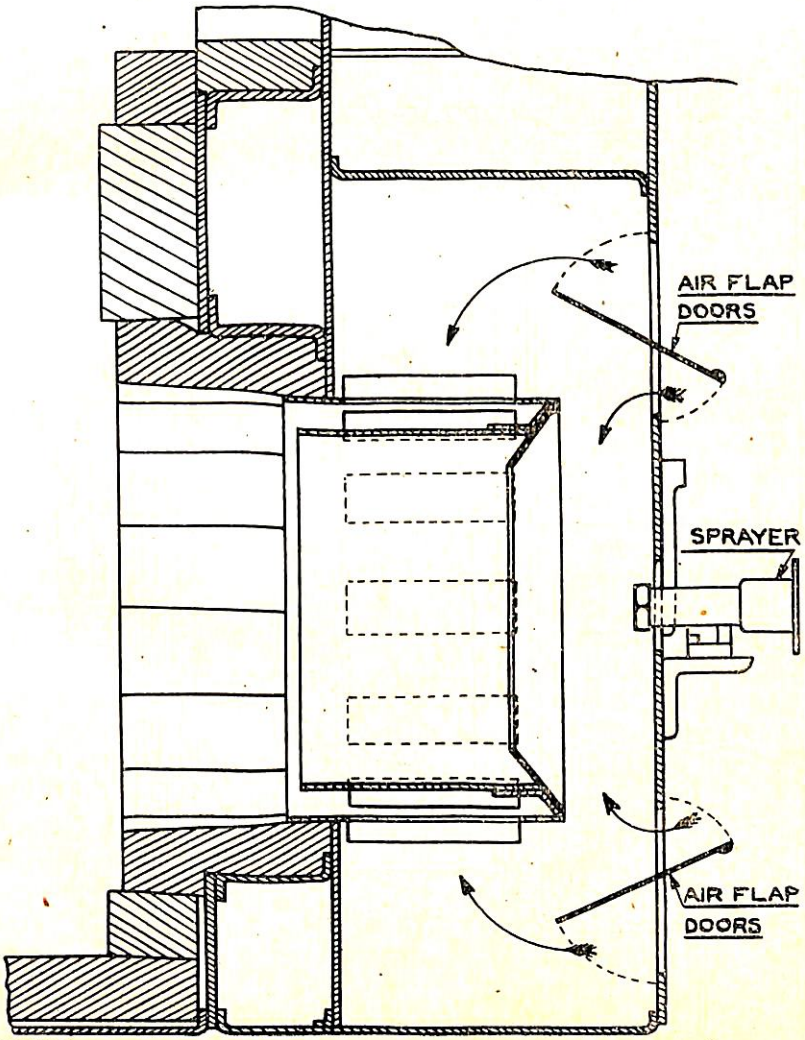
Some air passes through the combustion tube with the oil spray, but the amount is insufficient for complete combustion of the oil. A further quantity of air meets the burning spray as it leaves the combustion tube. In the earlier type of combustion tube, illustrated in Fig. 17, this extra air passes through slots in a steel tube, known as the air cone, which surrounds and supports the combustion tube. Vanes are fitted on this air cone to impart to the air a whirling motion, as it passes between the combustion tube and the air cone. It was considered that this would ensure better mixing of the extra air with the burning spray leaving the combustion tube. The name air cone originated with the first oil-burning arrangements fitted in the Navy. The extra air was admitted through slots in an

extension of the combustion tube. This tube was conical in shape and was given the name " air cone."

Each combustion tube is fitted in a separate air box on the boiler front, with two balanced air flap doors. These air flaps are

FIG:- 17.

BRICKLINED TUBE AND AIR BOX



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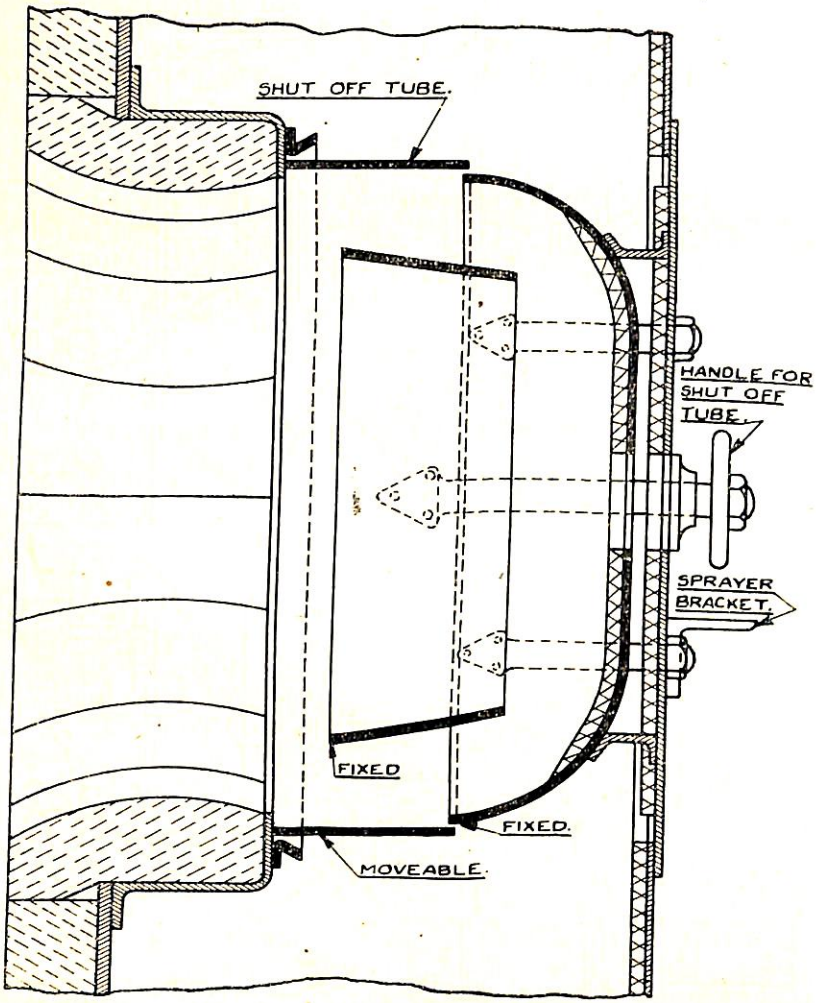
only opened to the sprayers which are in use, and close automatically if pressure in the furnace tends to blow the flame out into the boiler room.

Sometimes when an additional sprayer is put on to a boiler which is already alight, although the oil spray ignites, the flame does not spread back into the combustion tube. A sprayer should not

FIG:- 18.

COMBUSTION TUBE FOR PREHEATED AIR.



be allowed to continue burning in this manner, as combustion will not be completed in the furnace and overheating of the uptakes will occur. By momentarily closing the air flaps the flame can be brought back into the combustion tube.

With the new oil fuel sprayer an improved form of combustion tube was introduced. The air cone with its slots was done away with and the combustion tube is held in position by four supports from the boiler front. This type of combustion tube is fitted both with the open boiler front shown in Fig. 17 and has been adapted for use with closed boiler fronts, that is, for boilers in an open stokehold, and with air pre-heaters. Fig. 18 illustrates the arrangement for the control of the air supply to each combustion tube with a closed boiler front. As illustrated the air supply is shut off. When the sprayer is put on, the shut-off tube is pulled back by means of the two handles provided, until it touches the boiler front.

In the air boxes of open-fronted boilers fitted with the new pattern combustion tube, a deflector cone is fitted to lead the air, which passes outside the combustion tube, directly to the brick-lined tube. To prevent the accumulation of oil in the air box below the deflector cone, care must be taken that any gap between the inner end of the deflector cone and the brick-lined tube is filled with fireclay and crushed brick.

64. Smoke Mirror.—If the supply of air is insufficient, a lot of smoke will be made. This is most undesirable, not only on account of the loss of fuel entailed, but also because smoke may seriously interfere with the passing of signals, the accuracy of gunfire, etc. To enable the watchkeeper in the boiler room to see if smoke is being made, a small window is provided on each side of the uptake. Opposite the window in the back of the uptake an electric lamp is fitted, and opposite the front window a mirror. If no smoke is passing through the uptake, this light can be seen clearly in the mirror. A moderate amount of smoke will cause the light to appear a dull red, and with heavy smoke it cannot be seen at all. It is uneconomical to supply more air than is necessary for complete combustion, and the forced draught fans should be adjusted to supply only sufficient air to just not produce smoke.

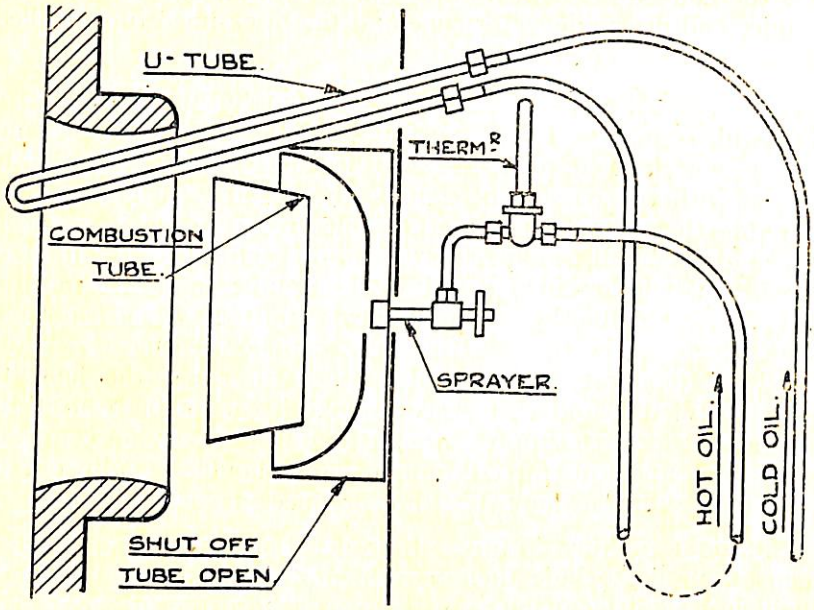
65. Smoke-making Fitting.—In order that ships may make a screen of smoke to hide their movements, arrangements are made by which a solid jet of oil may be injected into the furnace. The control valve for this smoke-making jet is made of a distinctive pattern, to avoid its being opened in mistake for the control valve to a sprayer.

When making prolonged smoke screens at low powers there is a possibility of oil fuel accumulating in the bottom of the furnace,

and this oil may find its way to the bilges through cracks on the furnace floor. The use of first one boiler and then another, when making smoke under these conditions, will prevent any large accumulation of unburnt oil. The bilges should be examined after the smoke making apparatus has been in use, to ascertain that they are free from oil.

66. Lighting up Oil-fired Boilers.—A hand pump is fitted in each boiler room for use *when no steam is available.* Also, as the steam heater cannot be used, a special fitting known as a U-tube is supplied, so that the oil can be warmed before it reaches the sprayer. This U-tube, with a special lighting-up sprayer of small output, is fitted in place of one of the normal sprayers. Fig. 19 shows a U-tube fitted in a boiler with a closed front. On an open-front boiler one of the two vertical air flaps of a centre sprayer is arranged so that it can be opened wide to admit the U-tube, which in this case passes through the inside of the combustion tube. A fire of oily waste is lit in the combustion tube to warm the oil in the

FIG: 19.



ARRANGEMENT OF U-TUBE FOR LIGHTING UP.

U-tube. The hand pump is worked slowly and a little oil allowed to drip from the sprayer on to the burning waste. As soon as the combustion tube and U-tube are warm enough, raise the oil pressure to 75 lb. per square inch, and open out the control valve wide. A thermometer is fitted to show the temperature of the oil after passing through the U-tube. The temperature can be increased by moving the U-tube further into the combustion tube, or decreased by drawing it out. Until steam is available to run a forced draught fan, air locks, etc., must be open, to allow a free access of air to the boiler room. On closed-front boilers special doors are fitted to facilitate the supply of air when lighting up.

Before lighting up an oil-fired boiler, it should be ascertained that there is no accumulation of oil in the furnace, or elsewhere in the boiler room. See that the water gauge glasses are in working order and the water level just above half glass. An air cock on the steam drum should be open, and also the superheater drains if fitted.

When steam is available in another boiler, a steam-driven oil fuel pump can be used, and a steam heater. There will, however, be some oil in the system between the heater and the sprayer. If this is burnt without being heated, a lot of smoke will be made. To avoid this a circulating valve is fitted in the control valve box, to allow of this cold oil being returned to the suction side of the pump. By circulating the oil in the system through the heater and back to the suction side of the pump, until the correct temperature has been obtained, smoke can be avoided. Before starting the oil fuel pump, it should be ascertained that all the sprayer control valves are shut, and all sprayers in position. As soon as the pump is started, the system should be examined for oil leaks, and if any are found the pump should be stopped. When satisfied that the drain water from the oil fuel heater is free from oil, put this drain on the reserve feed tank. If possible the forced draught fans should be started before lighting up, and it should be ascertained that the smoke mirror is correctly adjusted. When the oil has reached the correct burning temperature, shut off the circulating valve, adjust the oil fuel pressure to 50 lb. per square inch, and check the oil level in the air vessel if the pump is a reciprocating one. A sprayer may now be lit up ; one in the centre should be chosen. When the sprayers on the boiler are of large output, a smaller output sprayer provided for use in harbour, or a special lighting-up sprayer, are often used for raising steam. Except in emergency, steam should be raised slowly, not more than one sprayer being put on until the boiler has been connected to the others in use. Close the air cock when steam blows, and warm through a feed pump for use when required. The feed check valves and safety valve hand lifting gear should be worked while

raising steam, to ascertain that they are free. If a small output sprayer has been used for raising steam, it should be replaced by one of normal output as soon as the boiler has been connected.

67. Steaming an Oil-fired Boiler.—The *oil fuel pump* is adjusted to maintain the pressure ordered; this is generally 80 or 100 lb. per square inch. At full power, when all the sprayers have been put on, the oil pressure is increased as necessary to maintain the steam pressure required.

The steam pressure in the *oil fuel heater* is regulated to keep the correct oil temperature. It will generally be possible to keep the two lower drains on the oil heater closed, but it may be necessary to open the middle or lower drain at full power. The observation tank must be watched for any sign of oil leakage.

The *air pressure* should be just sufficient to prevent smoke. The more sprayers in use the higher will be the pressure to the furnace; the air pressure in the boiler room must therefore be increased, as extra sprayers are put on to maintain the required flow of air through each air box. The correct air pressure for any number of sprayers in use will be found by experience. To avoid making smoke, when putting on an additional sprayer, the air pressure should be increased before opening out on to the sprayer. Too high an air pressure will be indicated by white sparks from the flame, and may cause white smoke at the funnel. Air doors for sprayers not in use should be closed tightly.

A certain amount of *carbon* will be deposited on the combustion tube, and on the bricks around the hole or throat through which the flame enters the furnace. The glare of the flame will prevent such deposits being seen unless a coloured hand glass is used to look through. This carbon must be removed with the tools provided, and care must be taken not to damage the brickwork while doing this.

Oil must not be allowed to accumulate in the *air boxes*, as such accumulations of oil are liable to ignite and cause overheating of the boiler front. The air boxes of sprayers not in use should be examined to ensure that the control valves are not leaking. Special doors are provided on boilers with closed fronts, to allow of the removal of any oil which may accumulate at the bottom of the common air box.

If a sprayer becomes choked, it should be replaced by a spare. *If for any reason a sprayer is removed from a boiler, and no replace sprayer is available for immediate replacement, the sprayer pipe should be removed, and a screwed blank fitted to the connection on the oil-fuel sprayer-control valve manifold.* This will avoid risk of accident due to a wrong sprayer control valve being opened.

If at any time it is necessary to shut off all the sprayers, a torch

should always be used when putting on the first sprayer. If this is not done, and the sprayer does not ignite at once, there may be an explosion, due to the large amount of oil spray in the furnace when ignition takes place.

The *amount of oil in the tank* in use must be watched, and the watchkeeper should know which tank he can change over to in case there is a fault in the supply. Where more than one boiler is in use it is common practice to use two tanks, so that all the boilers shall not be affected by any defect in the supply from one tank.

68. Incorrect Burning of Oil.—Signs of incorrect burning should be watched for. The following are some of the faults that may occur, the probable cause, and the remedy:—

(1) *Oil dripping from sprayers.*—Caused by a defective or dirty sprayer, which should be replaced by a spare. Any oil in the bottom of the air box must be wiped up. If a sprayer drips when not in use, the control valve may not be properly shut or require re-fitting.

(2) *Wet combustion tube.*—The inner surface of the tube being covered with oil fuel is caused by either or all of the following:—

(*a*) Temperature of oil too low.
(*b*) Too much air.
(*c*) Position of sprayer incorrect, sprayer too far in or out of line.
(*d*) Sprayer defective or dirty.

(3) *Black smoke* is caused by—

(*a*) Insufficient air supply.
(*b*) Oil temperature incorrect.
(*c*) Combustion tubes or furnace throat obstructed.
(*d*) Defective sprayer or sprayers.

(4) *White smoke* is caused by—

(*a*) Excessive air supply.
(*b*) Water in the oil.

(5) *Extinguishing of oil fuel flame.*—Causes:—

(*a*) Water in tank or system passing through sprayer.
(*b*) Air passing over with the oil, owing to an overcharged air vessel.
(*c*) Solid matter choking the sprayer, due to failure of filter.
(*d*) Oil fuel tank empty.

If there is water in the oil, the combustion tubes will become coated with a frothy mixture.

(6) *Pulsation.*—This is a form of unsteady burning. The

oil burns with a series of small explosions which cause the boiler front to pulsate. If allowed to continue, some of the brickwork may be shaken down, and the oil supply pipes to the sprayers may be fractured. It can generally be stopped by increasing the air pressure. A reduction in the oil temperature and advancing the sprayers closer to the combustion tubes may also help to stop pulsation.

It is sometimes difficult to stop pulsation at high powers with the old pattern combustion tube. The opening of the air flaps can be adjusted with this type of combustion tube. Partially closing these doors will deflect more of the air through the slots in the air cone, and this will generally reduce the tendency of the flame to pulsate.

69. Fire in Boiler Room.—A small coal fire can be readily extinguished with water. An oil fire spreads more rapidly and the application of water will probably not extinguish the fire, and may spread it, as the burning oil will float on the water. Great care must therefore be taken to guard against the accumulation of oil fuel in the bilges, or elsewhere in the boiler room. The bilges are to be inspected frequently, and if at any time oil is detected, the fact is to be reported at once to the Engineer Officer of the watch or day.

To extinguish an oil fire, it must be smothered to cut off access of air to the burning oil. A small fire may be smothered with sand, and this is the best method of dealing with a small quantity of burning oil in an air box on the boiler front. For larger fires a chemical fire extinguisher of the foam type must be used. These are described in a later chapter. One or more should be available in each oil-fired boiler room, and all engine room department personnel must be acquainted with the method of operation.

If the fire cannot be extinguished with chemical fire extinguishers, it will be necessary to close down the boiler room to smother the fire. The oil fuel must be shut off; this can be done from outside the boiler room if necessary. If possible, all air flaps on the boiler should be shut before evacuating the boiler room. The fans should be stopped, and the air inlet flaps or shutters closed. The feed pump should be left running. The admission of steam to the boiler room will help to smother the fire. In destroyers and other small ships the drain cocks on the gauge glasses should be opened and the water cocks closed. In the larger ships steam fire extinguishers are fitted to admit steam to the boiler room bilge. A pipe from the auxiliary steam range is led to the bilge, with an open end below the floor plates. Two valves on this pipe are operated by a hand-wheel, which is arranged either close to the escape hatch from the boiler room or geared to the same position as the oil fuel emergency

valves. The first few turns of this wheel open the master valve, and a steam whistle comes into operation to warn the men in the boiler room. When the master valve is wide open, further movement of the wheel operates the stop valve and admits steam to the bilge.

70. Boiler Tube Leak Drill.—All watchkeepers in a boiler room should be familiar with the action to be taken in the event of a tube in a water-tube boiler becoming perforated or splitting. In order to ensure that prompt action is taken to meet this emergency, the following drill should be practised.

Action required in boiler room.—When the order is given, " Leak in the furnace No. boiler," the chief stoker or stoker petty officer of the boiler room is to—

(1) Shut off the oil supply to the burners and close and secure all shut-off tubes or doors, whether automatic or otherwise.

(2) Increase the speed of the fans.

(3) Open the safety valves on the injured boiler.

To ensure the greater safety of the men in the boiler room, he will be responsible that the boiler room hatch is not opened from below. If there is more than one boiler in the boiler room he is to take special care that the water level in the other boilers in use in that boiler room is kept at the correct height, the tendency being for all the feed water to go into the injured boiler.

The leading stoker or stoker in the boiler room is to—

(4) Increase the supply of steam to the main feed pump, if fitted in the boiler room.

(5) Start the auxiliary feed pump on the reserve feed tank.

(6) Open the auxiliary feed check valve on the injured boiler, and if other boilers in the same compartment are alight, close the main feed valve on the injured boiler.

(7) Make sure that the stop valves on the injured boiler are shut, whether self-closing or not, unless only one boiler is in use.

In the absence or any inability of any rating to perform his duties, the next senior rating is to take his place. In the case of one rating only being available, he is to carry out the whole of the above duties as expeditiously as possible. A report of the steps taken is to be made at once to the Engineer Officer of the watch in the engine room.

Where ashpit doors of coal-fired boilers have to be entirely removed for drawing ashes, great care should be taken to replace them as soon as possible.

Action required in engine room.—The Engineer Officer of the watch or senior rating in the engine room, on hearing the safety valves lifted, and seeing at the same time a rise of air pressure or a sudden fall of steam pressure, or receiving a report from the boiler room, is to—

(*a*) Station a man to prevent the boiler room hatches being opened from deck above.

(*b*) Keep a close watch on the level of water in the main feed tank and transfer water as necessary from reserve to main feed tank.

(*c*) Start steam extraction pumps if not already in use.

(*d*) Increase the supply of steam to the main feed pump where fitted in the engine room.

(*e*) Inform the bridge if it is necessary to reduce the speed of the main engines.

(*f*) Warn any other boiler rooms in which boilers are in use that an accident has occurred, and to pay particular attention to the water level in these boilers.

When an order is given "Leak stopped," the ratings in the boiler room are to revert to the conditions before the drill, by reducing the speed of the fan engine, shutting the safety valves, fire extinguisher, &c., and a similar course is to be pursued in the engine room.

Note.—The steps laid down in this drill are only to be put into actual practice when the leak is serious, *i.e.*, likely to endanger persons in the boiler room. In the case of a lesser leakage the fact should be immediately reported to the engine room, for the Engineer Officer to decide if the boiler is to be shut off.

If the drill be practised when engines are not under way, the procedure in the engine room is to be modified as necessary.

CHAPTER V.

WATERTIGHT SUB-DIVISION OF A SHIP AND THE STOWAGE OF FUELS.

71. Watertight Sub-division.—A warship is divided into a number of watertight compartments, so that in the event of the hull being damaged below the water line, say by gunfire, torpedoes or mines, collision or grounding, the inrush of water may be confined to the compartment which has been damaged.

The main transverse bulkheads, which divide the ship into main compartments, extend to the outer skin of the ship and up to the main or upper deck, and are known by numbers, the figures indicating the number of the frame at which they are situated. These transverse frames, which are fitted at about three feet apart on the inside of the shell of the ship to strengthen it, are numbered from the stem to the stern.

In larger ships main longitudinal bulkheads are fitted between certain of the main transverse bulkheads. In modern ships no doors are fitted in these main bulkheads below the water line, access to the lower compartments being through a watertight hatch in the deck.

Some of the main compartments are further sub-divided by minor fore and aft and transverse bulkheads. Watertight doors are fitted in these minor bulkheads and in the main bulkheads above the waterline.

72. Double Bottoms.—In addition to the above sub-divisions, all warships, except destroyers and other small vessels, have a watertight inner bottom, fitted about three feet inside the outer bottom, over a certain length of the ship. In battleships this inner bottom extends over nearly the whole length of the ship, while in small cruisers a double bottom is only fitted under the engine and boiler rooms.

Between the inner and outer bottoms, the transverse frames previously mentioned, and longitudinal frames running in the direction of the length of the ship, are riveted to the inner and to the outer bottoms. The longitudinal frames are numbered from the keel outwards on each side. The keel, the second and the fourth longitudinals are made watertight in way of the double bottoms. A certain number of the transverse frames between the inner and outer bottoms are watertight. The space between the inner and outer bottoms is thus divided into a number of watertight compartments, known as double bottom compartments. Manhole doors

are provided on the inner bottom to give access to the double bottom compartments, and large holes are cut as necessary in the non-watertight frames, so that the whole space is accessible for examination of the plates, etc.

Most of the double-bottom compartments are used for the stowage of oil fuel or reserve feed water. In any not used for these purposes, the plates and frames are prevented from rusting by coating them with red oxide paint or with thick oil.

73. Wing Compartments.—To guard against flooding of important compartments, due to damage of the ship's side below the waterline, additional longitudinal bulkheads are fitted close to the ship's side in the way of machinery spaces and magazines. The spaces between these bulkheads and the side of the ship are called " wing compartments." In large ships there may be three wing compartments, one abreast the other, along each side of the ship. Some of these are used for oil fuel, while others are empty and can be flooded from the sea, if necessary to correct a list on the ship.

74. Watertight Doors and Hatches.—For reasons of safety as many watertight doors and hatches, manholes, sluice valves, sounding tubes, etc., as practicable are kept closed at all times. All watertight doors and hatches are marked, so that the men detailed for the duties of closing them shall know which doors are to be closed. Valves on ventilation trunks communicating with a compartment are marked the same as the watertight doors of that compartment.

The following is the new system of marking recently adopted in H.M. ships.

" X," openings which may be closed consistent with leaving the ships in a condition that the routine can go on efficiently.

" Y," further openings which must be closed to bring the ship to the " action " condition.

" Z," further openings which must be closed to bring the ship to the highest possible state against gas.

" O," openings which are only closed on the order " close all watertight doors."

Special permission must be obtained before opening a watertight door or hatch, the marking of which indicates that it should be shut.

When hatches are open, it is of great importance to see that the catch for holding them up is properly placed, since lack of this precaution has been the cause of a number of serious accidents.

75. Stowage of Coal.—Coal is stowed in bunkers adjacent to the boiler rooms. Fixed or portable chutes are fitted, through which the bunkers can be filled from the upper deck.

To fill a coal bunker it is necessary for men to enter the bunker,

to trim the coal away from the chutes. Communication with the men in the bunkers is to be made at short intervals when the bunker is nearly full. Before the decks are washed after coaling, the lids of the coal chutes are to be replaced, to prevent water passing into the bunkers. Bunker lids are made watertight by smearing on the joint a mixture of white lead and tallow.

76. Quantity of Coal in Ship.—The quantity of coal on board is estimated from the volume occupied, on the basis of the following scale of measurement :—

One ton of Welsh coal occupies 40 cubic feet.

One ton of North Country coal occupies 43 cubic feet.

The quantity of coal used when coaling is checked, by measuring the volume of the coal when supplied in lighters, or by counting the number of bags of coal received and weighing 10 per cent. of the bags.

77. Ventilation of Bunkers.—All coal gives off inflammable gas which forms an explosive mixture with the air in the bunker, if it is allowed to accumulate. Ventilation pipes are fitted to allow the gas to escape, and additional ventilation is given for a few hours each week, by taking off the bunker lids. The formation of gas is more rapid for some days after coaling, due to the breaking up of the coal. For six days after coaling, the bunker lids should be removed every day for three hours.

No naked light is to be used in a coal bunker, or within 20 feet of any opening into a bunker, until it has been ascertained that the bunker does not contain inflammable gas. Bunkers are tested for the presence of inflammable gas by means of a safety lamp as described in the next chapter.

78. Spontaneous Combustion.—Some coals are liable to spontaneous combustion. Absorption of oxygen from the air causes a slow rise in temperature. After some days or weeks, the temperature in the middle of a mass of coal may rise sufficiently for the coal to start burning. Thermometer tubes are fitted, so that the temperature of the coal in the bunkers can be taken daily.

79. Stowage of Oil Fuel.—In capital ships sufficient stowage for oil fuel can be provided in the double bottoms and wing compartments. In cruisers, a certain proportion of the fuel can be stowed in the double bottom compartments under the engine rooms, and in some of the D.B. Compartments under the boiler rooms, but the larger portion is carried in compartments in the hold, both forward and abaft the machinery spaces. In destroyers, the main tanks are situated in the hold forward and abaft the machinery spaces.

In some destroyers, in addition to the main tanks, small *auxiliary or peace tanks* are provided just below the upper deck, on each side,

abreast the boiler room. When a diesel dynamo is fitted, one of these peace tanks is sometimes used for diesel fuel. Oil fuel is not carried in the peace tanks in time of war, on account of the risk of fire should one of these tanks be damaged.

The two auxiliary tanks in the after boiler room are generally used for carrying additional feed water instead of oil fuel.

80. Ventilation of Oil-Fuel Tanks.—Two ventilation pipes are fitted to each tank. These are led to the upper deck, where they are turned over and suitably baffled to prevent the entry of water or foreign matter, and fitted with wire gauze at the outlets.

81. Oil-Fuel Suction System.—In cruisers and destroyers a system of suction pipes extends from the foremost to the after tanks, with a connection to each tank and also to each pump, and any pump can therefore take its suction from any tank. Shut-off valves are fitted on this suction line, so that the forward pumps can take their supply from a forward tank, while the after pumps are on an after tank. It is preferable not to take the supply for all boilers in use from one tank. This avoids the possibility of failure in the supply, or water coming over with the oil, putting all boilers temporarily out of action.

In capital ships a fore and aft suction line is not fitted, and the fuel pumps in each boiler room can take oil only from the tanks abreast and under that boiler room, except that the pumps in the forward boiler room can also take oil from the double bottom and wing tanks forward of the boiler rooms. The oil in tanks abaft the boiler rooms can be transferred to any boiler room tanks through the oil-filling system, by means of pumps fitted in the engine room for this purpose.

Coarse strainers are fitted where necessary on the suction pipes, to prevent any foreign matter left in the tanks from reaching the pumps. The suction valves are of the screw down, non-return and flood type, so that tanks can be levelled off through the suction pipes. The valves can only be placed in the flood position by the removal of a locked guard. The oil-fuel suction pipes only extend to within about four inches of the bottom of the tank, to avoid sediment and water being sucked up by the oil-fuel pumps. Care must be taken to change over tanks before there is any chance of the oil-fuel pump drawing air in through the suction. The lowest depth to which a tank in use for the boilers can be pumped, depends on the shape of the tank and on whether the ship is rolling. It is not generally safe to pump down to less than a foot from the bottom when the tank is in use. If required, the remaining oil can be pumped over to another tank by a pump which is not being used to supply the sprayers.

82. Sounding of Oil-Fuel Tanks.—A sounding tube is fitted to each tank, and a sounding rod or steel tape provided. The tanks must not be filled to more than 95 per cent. of the total volume of the tank, the remaining 5 per cent. is to allow for possible expansion of the oil due to a rise in temperature. The sounding tube has a cap over the bottom end, to prevent the dropping of the rod damaging the ship's plating, oil being allowed access to the tube through a number of holes around the bottom of the tube.

83. Temperature of the Oil Fuel.—The temperature of the oil in all tanks is taken once a week by lowering a thermometer down the sounding tube. The temperature of the oil in tanks adjacent to boiler rooms in which steam is up is taken daily.

84. Steam Heating of Oil-Fuel Tanks.—In order that certain boiler oils which are very viscous at low temperatures may be used in H.M. ships, steam heating coils are fitted in all main fuel tanks. The suction pipes are lagged and have a small steam pipe fitted under the lagging. Either auxiliary exhaust, or reduced pressure live steam, can be used for warming the oil. This steam heating will only be required in very cold climates. The temperature to which the oil is heated in the tanks should not normally exceed 60° F.

85. Water in Oil-Fuel Tanks.—The oil fuel received should be free from water. Sea water may find its way into the tanks through a leak in the ship's bottom, or from the bilge in the case of double bottom tanks. All petroleum oils are lighter than water, so any water present will settle at the bottom of the tank. It is important that the presence of water should be detected, and the water pumped out before using the tank, as otherwise the sprayers may be extinguished. A special paste is provided, which is not affected by oil, but which changes colour on coming into contact with water. Tanks should be tested frequently by smearing some of this water finding paste on the lower portion of the sounding rod. This test should invariably be carried out when a tank is about to be put into use, and also after embarking oil fuel.

86. Residue Suctions.—In destroyers the sounding tubes of O.F. tanks are fitted with a hose connection, so that any water in the bottom of the tanks can be pumped out. In cruisers and capital ships a separate residue suction pipe is generally fitted to each tank. These pipes extend to within $\frac{3}{4}$-inch of the bottom of the tank and have a hose connection at their upper end. The hose connection on the sounding tube or residue suction pipe is connected to a fire and bilge pump, or to the main suction system, by means of special leather suction hoses. These fittings also allow of the fire and bilge pumps being used to transfer oil from

one side of the ship to the other to correct a list on the ship. The fire and bilge pumps should only be used for this purpose in an emergency. The normal method of transferring oil is by means of the oil-fuel pump, as described in the next article.

87. Oil Fuel Filling Arrangements.—In capital ships and cruisers a filling range is fitted, running fore and aft the ship, with hose connections on the upper deck, and a lead to each tank. Isolating valves are fitted for shutting off the forward and after end of the range when not required, or if damaged. The oil fuel filling system is designed for a working pressure of 200 lb. per square inch, but a pressure of 75 lb. per square inch at the pumps in the oil tanker should not be exceeded when oil is being pumped through a hose. To prevent a pressure being put on the tank, the branch to each tank is broken some way above the tank, and an open funnel fitted. A sluice valve is fitted where the pipe from the funnel joins the tank. The flow of oil to the tank is controlled by a valve on each branch just above the funnel. Care must be taken that these filling valves are not opened too wide, especially when the tank is nearly full, or oil may overflow from the funnel.

A filter is fitted where the branches from the upper deck join the filling range. If the filter is of the type which has to be opened out for cleaning, two are fitted on each branch with the necessary shut-off valves.

In destroyers an oil fuel filling system is not fitted, but a branch is carried from the oil fuel suction system to the upper deck at each end of the ship. By connecting the hose from the oiler on to one of the branches, any tank can be filled through the suction system, by opening the suction valve to the flood position.

88. Embarking Oil Fuel.—Before the oiler comes along, the goosenecks on to which the oiler's hoses will be connected are fitted on the upper deck connections to be used. The leather jointing rings of these connections must be inspected, and every care taken to prevent a leak of oil on to the deck. Trays will be found useful to catch any drips from the hose connections. If the deck is a wooden one, it should be covered with old painted canvas if such is available. If a wooden deck is kept wet, any oil spilt will not be absorbed into the wood ; care must be taken that water does not enter the filling system. Oil marks on a wooden deck are best removed by painting them over with a thick coat of lime-wash. This wash should be allowed to dry, and should not be removed for at least twelve hours.

When the oiler is secured alongside, the hoses are connected, and the tanks in the oiler from which oil is to be taken dipped, in order that the amount of oil received may be checked. If it should be necessary to lead the hose past the galley, care is to be

taken that there is no leakage in the vicinity, and galley doors are to be closed.

A stoker petty officer is stationed in the oil tank vessel in charge of the discharge valve, which is to be opened slowly until it is seen that the flow of oil into the tanks is regular and constant. At least two men should be stationed to pass the word to shut off the discharge valve, in case it may be found necessary to do this quickly.

A stoker petty officer is also stationed at each tank that is being filled, and he is held responsible for taking the soundings, and as the filling of each tank nears completion, he is to ensure that the oil flow is eased, and that the tank is not filled to more than 95 per cent. of its full capacity.

When fuelling is nearly completed, the man in charge of the pump in the oiler should be warned to reduce the oil fuel discharge pressure. It is generally possible for the oiler to suck oil back from the hose before disconnecting it. A plug screwed into the end of the hose will prevent oil running out while the hose is being passed back to the oiler. On completion of fuelling the oil fuel filling range should be drained.

To expedite fuelling in destroyers, a few of the larger tanks are sometimes filled through an additional hose, led in from the oiler through a scuttle on the ship's side and into an open manhole on the tank. In this case at least 6 feet of hose should enter the tank, and to prevent the end of the hose jerking out of the tank, a wooden toggle should be lashed at right angles to the hose, 2 or 3 feet from the end of it, the toggle being placed after inserting the hose in the tank. In addition a temporary guard must be secured across the manhole.

It should be noted that the nuts on the studs for the manhole covers of oil fuel tanks are of circular shape, necessitating the use of special spanners to remove them. The rating in charge of oil fuel is generally held responsible to the Engineer Officer for the safe custody of such special spanners.

Before opening the manhole doors of oil-fuel tanks preparatory to taking in oil fuel of any description, all stoves and naked lights, in or near any compartment through which the oil fuel hoses pass, are to be extinguished, and are to remain so after oiling is finished, until it has been ascertained definitely that no oil fuel vapour is present in the compartment immediately above the tank which is being filled.

After oiling is completed an inspection should be made of spaces adjoining oil-fuel tanks, in order to ascertain whether any leakage of oil exists. This examination should be repeated daily for a few days and afterwards at longer intervals.

89. Transfer of Oil Fuel.—The transfer of oil from the double bottom and wing tanks abreast the engine rooms in capital ships to the boiler room tanks has been mentioned in article 81. There is also a connection to the filling range from the discharge side of each boiler room pump, in both cruisers and capital ships. Any oil fuel service pump, not in use for supplying the boilers, can be used to pump oil from one tank and transfer it through the filling range to any other tank. A serious fire occurred in one ship through a tank overflowing in a boiler room in which boilers were alight. When pumping over oil to a steaming boiler room, pumping to a tank of which either the filling funnel or the sounding tube are situated in the boiler room is to be avoided if possible.

By connecting a hose to the filling system, the oil fuel service pumps and transfer pumps, if fitted, can be used to pump oil out of the ship to a lighter or to another vessel. When pumping oil out of the ship, the filter between the filling range and the upper deck connection being used should be by-passed, or, if this is not possible, the filtering cartridge is removed from the filter to be used.

It has been the general practice to provide for the fire and bilge pumps in engine and boiler rooms being used to transfer or discharge oil, when the oil-fuel service pumps were not available or were of insufficient capacity. The connections from the fire and bilge pumps to the oil-fuel suction system, and to the filling system, are always made portable, and are only connected up if required. It is not desirable to have to pump oil with a pump which is normally used to supply water for fire service and for washing decks. In new battleships and cruisers portable oil-fuel suctions and discharges are not provided for the fire and bilge pumps. Oil-fuel transfer pumps fitted in the engine room, and oil-fuel service pumps not required for the boilers, can meet all requirements for transfer or discharge of oil fuel.

The latest rotary oil-fuel service pump can be used as a two-stage pump to supply oil to the boilers at a pressure of up to 150 lb. per square inch, or as two single-stage pumps giving a larger output at a lower pressure for transferring oil. When used as a two-stage pump, the first-stage discharges to the suction side of the second stage. By means of two change-over valves, the discharge of the first stage can be allowed to by-pass the second stage, and the suction side of the second stage opened to the suction pipe.

In destroyers the number of oil-fuel tanks is relatively small, and the necessity to transfer oil from one tank to another, or to discharge oil fuel to another vessel, does not often arise. Peace tanks, being higher than the main tanks, can be run down to any main tank through the oil-fuel system. Main tanks can be levelled off through the suction system, but it is not possible to transfer all

the oil from one main tank to another by this means. An oil-fuel service pump can be used to pump oil from a forward main tank to an after main tank or vice versa, through a cross connection between the oil-fuel discharge systems. In both the forward boiler room and the after boiler room a connection is provided between the discharge system and the suction system. With the suction bulkhead valve between the boiler rooms shut, a pump in the forward boiler room can take oil from any forward tank and discharge through the after boiler room and the after length of suction pipe to an after tank. The suction valve of the tank to which oil is being pumped must be opened to the flood position. In emergency the fire and bilge pump can be used to transfer oil.

The oil-fuel service pumps, not required for the boilers can be used to discharge oil to an oil lighter or another vessel. A pipe is carried from the discharge side of each pump to a deck plate on the upper deck to which a hose can be connected. To enable this pipe to be emptied after it has been used, a drain is fitted from the bottom to the suction side of the pump.

90. Cleaning of Oil-Fuel Tanks.—Oil-fuel tanks are cleaned periodically, and prepared for survey of dockyard officers, at intervals as laid down in the Engineering Manual. Before a tank is opened, it is first emptied as far as possible with the pumps provided. The suction and filling valves are then to be shut and lashed. *No naked light is to be permitted within 20 feet of the manhole doors, and no one is to enter the tank until it has been thoroughly ventilated and tested by means of a safety lamp.* A ventilating fan is to be in continuous use while any person is in the tank, and communication is to be maintained with a man stationed outside the tank. Materials liable to leave pieces which would choke the filter are not to be used for cleaning the tanks, canvas, cotton, woollen or linen rags, old bunting, towelling or fearnought are suitable for this purpose.

Contact with oil fuel may in certain cases cause skin affection. Oil skin combination suits are provided for men employed in oil-fuel tanks. Clothing saturated with oil fuel should not be worn, and care must be taken to thoroughly cleanse the skin after work. Any cuts or abrasions should be washed carefully, disinfected with iodine, and protected with a bandage. Any man noticing any irritation of the skin, or inflammation of a cut, should report to the Medical Officer.

91. Petrol and Paraffin Precautions.—Very special precautions are necessary when aviation spirit or petrol are carried on board, as these fuels give off a large quantity of inflammable vapour at atmospheric temperature. *If a little petrol is spilt, or left exposed to the air in a compartment, it will quickly evaporate and fill the*

whole compartment with an explosive mixture. Any materials used for soaking up petrol must be disposed of at once, preferably by burning in the open air, stringent precautions being taken to control and prevent any spread of the fire.

In addition to the danger of an explosion with petrol vapour, the breathing of air containing an appreciable quantity of such vapour will cause intoxication and eventually insensibility.

If a man's clothing becomes saturated with liquid petrol, he should at once change, otherwise the skin will be affected and hours later large blisters will appear.

A compound of lead is added to the fuels used for aircraft. Such fuels are said to be doped and are coloured to distinguish them from undoped fuels. Particular care must be taken to avoid bodily contact with doped petrol.

On account of the danger of carrying petrol onboard, for some years a less volatile fuel known as mineral vaporising oil was used for the motor boats. This fuel closely resembles paraffin used for lamps, and the name "paraffin" is commonly used both for the lamp oil and for mineral vaporising oil. Although the chances of an explosion with mineral vaporising oil or paraffin are much less than with petrol or aviation spirit, the same precautions must be taken when any of these fuels are carried onboard.

92. Storage of Petrol and Paraffin in Cans.—When only a small quantity of petrol or paraffin was carried for motor boats, it was drawn in five-gallon cans which were kept in locked racks on the boat deck.

Cans for petrol or paraffin, whether empty or not, are to be kept closed and stowed in those racks and no smoking or naked lights are allowed in the vicinity of the racks. Duplicate keys for the racks are kept in a glass-fronted box near the rack, in order that the racks may be unlocked quickly, and the cans thrown overboard in the event of a fire in the vicinity. Petrol cans are distinguished from paraffin cans by being painted with a red band.

93. Petrol and Paraffin Tanks.—Many ships now have to carry aviation spirit for aircraft, as well as a considerable quantity of petrol for motor boats. Stowage for these fuels is now arranged in large tanks fitted in a compartment below the water line, generally at the forward end of the ship. From the top of each tank a breathing pipe or vent is led to the ship's side, with an anti-flash fitting over the end. Fuel is forced through a supply pipe from the bottom of the tank to a position for fuelling the aircraft or boats by pumping air into the top of the tank, after closing the vent. After use, the supply pipe must be emptied by connecting a hose from the air main to the end of the pipe, and blowing the fuel back to the tank.

The tanks are filled through a branch from the supply pipe to a connection on the upper deck.

A compartment containing aviation spirit, petrol or paraffin tanks, or the control arrangement for the distribution of these fuels, is known as a petrol compartment.

Petrol compartments are treated as magazines. The keys are kept on the magazine keyboard and only issued to authorised persons. No naked lights, matches, wandering leads or electric torches are to be taken into a petrol compartment. Magazine hand lamps only are to be used. Anyone entering the compartment is to wear rubber boots or shoes, and is not to carry any steel tools.

Detailed instructions regarding the inspection of petrol compartments, and the precautions to be taken when petrol or paraffin tanks are opened for cleaning, will be found in the Engineering Manual. The tanks are to be flooded three times before opening. To ensure complete clearance of fuel and vapour, the flooding must be continued until water flows from the air-escape pipes. No one is to enter these tanks until the Engineer Officer has satisfied himself that they are safe for entering.

Petrol and paraffin tank washings should not be discharged overboard whilst the ship is at anchor, if there is a possible risk of fire from fuel in the washings, which will float on the surface of the sea.

94. Embarkation of Petrol and Paraffin.—When petrol or paraffin are being embarked or discharged smoking or naked lights must not be allowed in the vicinity of the filling or venting position, and the other precautions laid down in the Engineering Manual are to be strictly observed. No tank is to be filled in excess of 95 per cent. of its capacity.

CHAPTER VI.

THE SAFETY LAMP AND PRECAUTIONS WHEN ENTERING OR WORKING IN CONFINED SPACES.

95. Explosive Gases.—The gases given off by coal, fuel oils, and lamp oils are inflammable. Lubricating oil will also give off inflammable gas if it becomes hot. Corrosion in a vessel containing fresh or salt water may give rise to hydrogen, which is an inflammable gas. Mixtures of these inflammable gases and air, if brought in contact with a naked light or spark, will explode. If precautions are not taken to guard against such explosions, serious damage and probably loss of life will result.

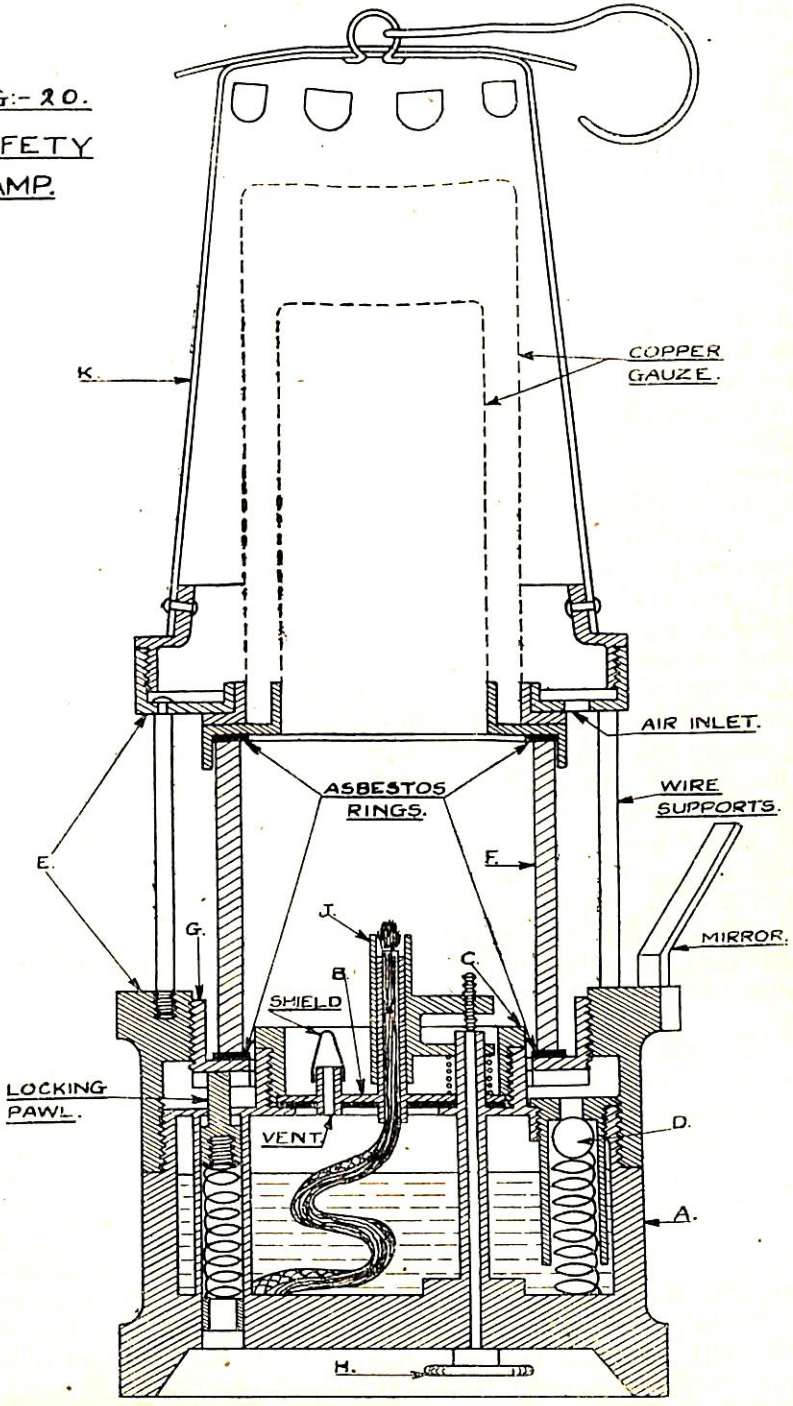
Two of the gases used in refrigeration machinery, ammonia and methyl chloride, will form explosive mixtures with air. Ammonia machines will only be found in a few of the older ships, and they are always fitted on the upper deck. The effect of ammonia on the nose and eyes is such that its presence will be evident long before there is sufficient present to form an explosive mixture. The addition of a strong-smelling compound to methyl chloride is now being tried, in order to provide a safeguard against the possibility of an explosion with this gas.

96. The Safety Lamp.—The safety lamp derives its name from the fact that, provided the necessary precautions are taken, it can be safely used in a space where an inflammable gas is present. It can also be used to ascertain whether there is any inflammable gas present, and it is for this purpose that it is generally used. The lamp was first introduced for use in coal mines, on account of the risk of explosion due to the presence of an inflammable gas known as firedamp. The special feature of the lamp is that the flame is shielded from the air surrounding the lamp by copper gauze, through which the air must pass to reach the flame. As a flame will not pass through copper gauze, the flame of the lamp cannot ignite any inflammable gas which may be surrounding the lamp. To make doubly certain that the lamp is safe, two layers of copper gauze are fitted.

Fig. 20 shows a safety lamp in section. The oil reservoir A has a lid B, which carries the wick, and is held down by the screwed sleeve C. This lid is only removed when necessary to fit a new wick. The reservoir is filled with mineral sperm oil, by pressing down the ball valve D with the end of the small funnel provided. After filling the lamp, all surplus oil must be wiped off the top of the reservoir. The upper portion of the lamp E carries the glass

FIG:- 20.

SAFETY LAMP.



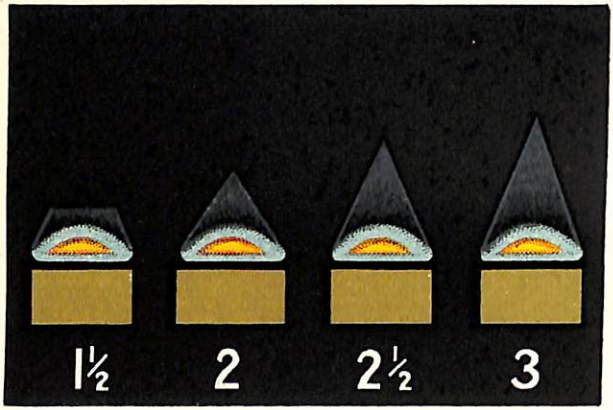
shade F and the two copper-gauze cylinders. These are held in place by the screwed sleeve G. The brass wire supports, which connect the upper and lower portions of E, form a guard for the glass shade. On the bottom of G is cut a ratchet, which engages with a locking pawl. When, after lighting the lamp, the upper portion E is screwed on to the oil reservoir, the locking pawl prevents the lamp being opened without a special key. This key has a threaded end, which can be screwed into a hole in the locking pawl. To open the lamp, the key must be inserted, and the pawl pulled down so that it does not engage with the ratchet. By means of the thumbscrew H on the underside of the oil reservoir, the height of the hood J, surrounding the wick tube, can be adjusted to control the size of the flame. A small mirror is fitted to enable the flame to be seen when the lamp is lowered into a tank. To protect the wire-gauze cylinders, a steel plate shield K is screwed into the upper portion of the lamp. This shield is fitted with a hook, to facilitate carrying and suspending the lamp.

A special key is provided for unscrewing sleeve G, when it is required to remove the glass shade or gauze cylinders for cleaning. This sleeve has a left-handed thread. An asbestos jointing ring is fitted on the top and on the bottom of the glass shade. Sleeve G must be screwed up tight, so that no air can reach the flame of the lamp except by passing through the gauze. The gauze cylinders must be kept clean, and care must be taken that they are not damaged in cleaning. If paraffin is used for cleaning, all traces of this must be removed from the gauze before the cylinders are replaced in the lamp.

Before issue from the store safety lamps are to be lit and locked, and the key for opening the lamp is to be retained by the storekeeper. The person drawing the lamp should verify that the top of the reservoir is free from oil, that the glass shade is intact, and that the gauze cylinders are clean and whole. If the lamp does not burn properly it should be returned to the store.

97. Indication of Inflammable Gas.—Not only can a safety lamp be taken into a space containing an explosive mixture without causing an explosion, but also the lamp will indicate the presence of inflammable gas. It is evident that if the lamp is surrounded by an explosive mixture, some inflammable gas must enter the lamp. This gas will burn inside the wire gauze, and will form what is known as a "cap" above the normal flame of the lamp. A cap on the flame will therefore indicate the presence of inflammable gas, and the quantity of inflammable gas present can be judged by the height of the cap. Inflammable gas, if present, will probably burn with what is known as a non-luminous flame, and a cap on the flame may not be noticed unless it is carefully looked for.

FIG. 21.



The figures show the appearance of "caps" visable in air containing 1½ per cent., 2 per cent., 2½ per cent. and 3 per cent. of firedamp respectively.

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Malby & Sons, Lith.

To ensure that if there is a cap on the flame it is visible through the glass chimney, before entering the space to be tested, the flame of the lamp is turned down, until only a faint line of blue is seen over the yellow centre, as illustrated in Fig. 21. The cap formed by hydrogen is particularly difficult to see, and will probably not be observed if there is any other light in the space beyond that from the drawn down flame of the safety lamp.

If 1 per cent. of inflammable gas is present, the cap will be just large enough to be visible. Although this quantity of inflammable gas is insufficient to form an explosive mixture, the lamp should be removed, and ventilation of the space continued until no cap is found on testing with the safety lamp.

When only a small percentage of inflammable gas is present, a mistake may easily be made, unless the observer makes himself quite familiar with the appearance of the lowered flame as seen in the pure air.

When a distinct cap is seen on the flame of a safety lamp, the lamp should be handled with caution and moved slowly to a place of safety, and if the cap is so high as to show that the lamp is filled with gas, the greatest care should be taken, for the lamp is then in a very dangerous condition. The lamp should be carried at once to pure air and should on no account be jerked or moved rapidly, because a jerk is likely to ignite gas outside the lamp, and cause an explosion. If it is impossible to remove the lamp to a place of safety and it is thought necessary to extinguish it, this should be done by lowering the flame and gently folding the lamp in a jacket, or wrapping a cloth round the ventilator holes, so as to smother the flame.

The percentage of inflammable gas present may be so high, that it may cause the lamp to be extinguished. In every case, therefore, in which either the flame cap or the extinction of the flame indicate the condition of the air under test to be unsatisfactory, the lamp must be withdrawn from the space under test, which must be again ventilated, so that on a repetition of the flame test the atmosphere is shown to be free from inflammable gas.

98. Foul Air.—If air does not contain sufficient oxygen to support life, it is said to be "foul." A lamp or candle will not burn in foul air, and this test is used to ascertain whether it is safe to enter a compartment in which foul air may be present. In making this test a safety lamp must be used to guard against an explosion, in case there should be any inflammable gas in the compartment.

Normally foul air will only be found in a compartment or vessel into which a free circulation of atmospheric air has not been possible. Human beings absorb oxygen from the air by breathing. If men

are employed in a compartment which is inadequately ventilated, the oxygen may be used up at a greater rate than it is replaced by an inflow of fresh air.

Paint whilst drying absorbs oxygen from the air, and if a compartment is closed up after painting, and kept closed for some time, the air in the compartment will become foul.

Cases also occur where the air is expelled from a compartment by the gases given off by rotting vegetable matter, or by the gas escaping from refrigerating machinery. Such gases, being heavier than air, will not be dispersed unless a current of fresh air is caused to flow through the lower portion of the compartment.

In an explosion all or most of the oxygen in the air is used up, and it is therefore dangerous to enter a compartment in which there has been an explosion, until it has been well ventilated.

A bogie or a stove in a compartment also uses up the oxygen, and unless there is a free escape for the gases from the stove and a steady supply of fresh air, the atmosphere in the compartment may become dangerous. When fuel containing carbon is burnt with a restricted supply of air, a gas known as carbon monoxide may be formed. It must be borne in mind that carbon monoxide is odourless, and that it is a deadly poison even when present only in traces. Carbon monoxide is present in the exhaust of internal-combustion engines, and it is very dangerous to allow the escape of such exhaust into an enclosed space. Carbon monoxide will also be present in a boiler which has been closed up with trays of burning charcoal inside.

An ordinary gas-mask is no protection against foul air or carbon monoxide. Two types of breathing apparatus are supplied which enable a man to enter with safety a compartment containing foul air or carbon monoxide. Pattern 230 Breathing Apparatus consists of a gas mask face-piece with a long air inlet tube, the open end of which is left outside the compartment; while with the Salvus Breathing Apparatus the wearer carries a small flask of oxygen. All ratings should be proficient in the use of a pattern 230 Breathing Apparatus and should know where these are kept. A Salvus Apparatus should be used only by those who have received training in the use of this apparatus.

99. Precautions before Opening a Confined Space.—*Before any space, such as a double-bottom compartment, wing space, coal bunker, oil-fuel tank, main or reserve feed tank, boiler, evaporator, distiller, condenser, main inlet, store room, or the crank chamber of a forced lubrication engine is opened, it must always be seen that there are no naked lights of any description within at least 20 feet of the door or cover which is to be opened, in case there may be an inflammable gas present.*

Compartments, such as turret or bathroom drain tanks, in which oil or soapy water are collected, should be completely flooded with sea water to expel any foul air or explosive gas present, and pumped out immediately before opening them. If time permits and if desired, such tanks can again be flooded and pumped out. When adopting this procedure, any air escape or vent pipes from the tanks which terminate in a living space should be fitted with temporary lengthening pieces, so that escaping gas may be discharged into the open air, care being taken that there are no naked lights within at least 20 feet. It should be ascertained, by watching the end of the vent pipe, that the tank is venting properly when it is being flooded and pumped out.

The flooding of oil fuel tanks is undesirable, as salt water may be left in suction pipes and cause corrosion. It may, however, be done if the Engineer Officer considers it necessary. *Tanks used for the stowage of petrol and paraffin are always to be flooded before opening.* (*See article* 93.)

When a confined space has not been flooded before opening, it must be thoroughly ventilated by means of an air fan with hose. In the case of compartments which have not been opened for a considerable period, a good current of air is to be supplied, and the compartment is to be left open for some time, preferably 24 hours, before any attempt is made to enter it to carry out the safety tests. Particular care is required when ventilating spaces with only one opening.

100. Test with Safety Lamp.—*To ensure that the flooding or ventilation of a confined space has completely dispersed any inflammable gas which may have been present, the space should be tested with a safety lamp before any naked light is used inside the space or within 20 feet of the opening.*

The safety lamp is first to be held in the upper part of the space, and then lowered by a line to the bottom. If the lamp will burn steadily in these positions, the compartment may be entered by the rating carrying out the further tests, care being taken to maintain constant communication with men outside the space. The flame of the safety lamp is then to be observed when it is held in the upper and lower parts of each bay of the compartment or space. If there is any indication of the presence of dangerous gas, the space is to be left immediately and further ventilated, until on further tests being made, the lamp will burn steadily in all parts of the space. Should the person making the tests with the safety lamp fail to maintain communication with those outside the compartment, immediate steps are to be taken to rescue him.

Pattern 230 or the Salvus Breathing Apparatus must be worn by those entering a confined space to rescue a man overcome by foul air.

101. Working in a Confined Space.—When men are to work in a confined and badly ventilated compartment, the chief stoker, or stoker petty officer, in charge of the party is responsible for seeing that all necessary precautions are taken before the men are allowed to enter the compartment.

After testing the compartment with a safety lamp, a further test is to be made with a candle, except in the case of fuel tanks. A lighted candle is to be placed in the compartment, and the flame is to be carefully watched for a period of five minutes. If the candle burns clearly and steadily for this time it shows that the air is fit for breathing, and men may be allowed to enter the space for work. If however the candle does not burn steadily or goes out, it indicates that there is insufficient oxygen in the space. Further steps must be taken to ventilate it thoroughly, and then the test must be made again. It must be most carefully noted that naked lights are never to be used in or near fuel tanks, and when testing these the lighted candle test is not to be carried out.

Irrespective of any alternative form of illumination, candles are to be kept burning where the men are working in a confined space, and the men are to be warned that if any candle begins to burn dimly the compartment should be vacated immediately. On no account should lamps be used as the source of illumination, as if these commence to burn dimly it may erroneously be assumed that the lamps are running short of oil or are in need of trimming, whereas the actual cause of decreased illumination may be the lack of oxygen in the space. It is most dangerous to use in such spaces bogies or any form of burning fuel. Communication is always to be maintained between the men working in the compartment and someone outside. Special caution is necessary when the compartment has only one exit.

102. Red Lead.—In view of the injurious effect of red lead paint on the health of men employed in confined spaces, its use is restricted as much as possible. Oxide of iron paint (unless other approved material is supplied) is used in double bottoms, wing passages and other confined spaces on board ship, but red lead is used for painting the portions of frames, girders, etc., where its use will not be injurious to the men.

103. Precautions against Metallic Poisoning.—The following precautions are to be observed by men working in confined spaces where lead paint has been used, and by men employed in red leading, or exposed to special risk of metallic poisoning, in order to prevent the introduction of lead into the system through the skin, or through food, or through breathing dust from the paint :—

(1) Absolute cleanliness is necessary.

(*a*) Face and hands should be frequently washed with

hot water and soap, nails scrubbed with nail brush, mouth rinsed with water, and a hot bath taken at least once a week.

(*b*) Working suits should be worn while at work, and should be washed at least once a week.

(*c*) No food of any description should be eaten where scaling or painting is going on.

(*d*) Hands and lips should be washed before eating, nails scrubbed, etc.

(*e*) Teeth should be well scrubbed with a tooth brush at least twice daily.

(*f*) A mask of clean muslin or bunting should be worn when working in an atmosphere containing lead dust, etc.

(2) Men employed as above should be inspected periodically by the Medical Officer.

(3) Oily food, such as milk, bacon, etc., should be taken by men so employed.

(4) No man should commence work on an empty stomach.

(5) Men who have had to handle red or white lead are to wash immediately afterwards.

(6) Attention is drawn to the necessity of all possible precautions being taken in all cases of exposure to the danger of lead or other metallic poisoning, whether by absorption through direct contact, or by inhaling dust or fumes, *e.g.*, when working hot rivets through red lead, as well as when painting, scaling, etc. Surfaces which are coated with *zinc oxide paint* are not to be scrubbed with wire scrubbers, unless the mouth and nostrils of the operator are covered with a respirator. This is to be of a simple type, made in the Sick Bay of two-fold lint or flannel with cotton wool between, to serve as an obstruction to prevent the poisonous dust of zinc oxide being inhaled.

CHAPTER VII.

PRECAUTIONS AGAINST FIRE—FIRE EXTINGUISHERS.

104. Fires and their Causes.—Thousands of lives are lost, and millions of pounds' worth of damage done, every year by fire. The results of an outbreak of fire on board ship are likely to be even more serious than on shore. Nearly all fires are caused by carelessness, such as :—

(*a*) Leaving combustible material where it may become ignited by hot pipes or flues, or by sparks or heat generated by friction.

(*b*) Smoking or the use of naked lights in improper places.

(*c*) Carelessness in the disposal of cigarette ends and matches.

(*d*) Neglect of the proper precautions in the use of fuel oils and inflammable liquids.

A fire may also result from spontaneous combustion or from the overheating of an electric lead.

105. Combustible Matter not to be placed in Ventilators.—Oakum, paper, articles of clothing, or any other combustible matter, is not to be placed in ventilators, or in any holes or on ledges that are not easily seen, as a fire might be caused by the spontaneous combustion of any of these articles. To guard against accumulations of dirt and rubbish, guards for protecting fan impellers are to be cleaned frequently and all ventilators are to be examined periodically.

106. Oil Lamps. Mineral sperm oil is to be used for all closed lamps. For open lamps, which are now rarely used, rapeseed oil is supplied. Lamps should never be extinguished by means of a piece of oakum or rag put on the flame, as portions of the burning wick are likely to adhere to the oakum, and after smouldering for a time, may eventually burst into flame.

107. Spontaneous Ignition of Cotton Waste, etc.—Cotton waste, which has been used for wiping up oil, is very liable to become ignited due to the heat developed by the rapid oxidation of the oil. Cotton waste and similar fibrous and porous materials when saturated with oil, must therefore be considered as liable to spontaneous ignition, and after use such wipings are to be destroyed immediately, or stowed in the special iron bins provided.

The probability of spontaneous ignition of a mass of porous fibres such as cotton, cotton wool, cotton waste, jute, hemp, etc., is increased when the fibre is stored in bulk and is subjected to heavy pressure,

while minute sparks caused by striking the iron banding hoops of bales of such materials have been known to cause ignition.

108. Storage of Inflammable Liquids.—A special store-room is generally appropriated for the storage of spirits of turpentine, varnishes, compositions for the ship's bottom and any other highly inflammable liquids, but if it is not possible to arrange a special store-room for these, they are stored in special fittings in the spirit room. *Naked lights are never to be used in places where such inflammable liquids are stored,* and these liquids are only to be drawn off from any cask or vessel in daylight on the upper or main deck, well away from any fire or lights. A safety lamp or magazine hand lamp should be used for illumination in case of necessity.

The casks and cans used for each description of oil and composition must be painted the distinguishing colour authorised for each, and when issued to ships must be fitted with screw bungs or lids in accordance with the established patterns. Oils and tar are also to be drawn in iron casks with screw bungs.

A label, denoting the contents and bearing the words, " inflammable—no light to be brought near this," should be attached before issue to every drum, cask, or can which contains any inflammable liquid. Inflammable stores are to be drawn and kept on board in the approved drums or cans only.

Casks, etc., containing inflammable liquids are not to be filled completely, sufficient space being left for the liquids to expand under increase of temperature.

On emptying, casks and cans are to be drained completely, and after cleaning and oiling the screw bungs or screw lids these are to be screwed up tightly to exclude air and to keep the cans clean for further use. (*See* articles 92 and 93 for storage of petrol and paraffin.)

109. Coal Bags.—To prevent sufficient heat being generated to cause spontaneous ignition by the oxidation of the coal dust remaining in them, used coal sacks and bags (which, in order to preserve them, are always to be quite dry when stowed) are to be removed and ventilated from time to time.

110. Prevention of Fire in Motor Boats.—(1) *Naked lights.*—In petrol-engined ships' boats, including those attached to shore establishments, smoking is prohibited at all times in all parts of the boat. No oil lamps, or naked lights of any description, except the steaming lights, are to be used on board.

In larger petrol-engined boats, where the crew live onboard, smoking is permitted at certain times in parts of the boat remote from the petrol engines. Local orders are issued as to when and where smoking is allowed in these boats.

In paraffin-engined boats smoking is prohibited at all times in the engine compartment. Smoking is prohibited everywhere on-board when taking in or discharging fuel or when the fuel tanks are open.

(2) *Fuel.*—Only electric lamps, the fittings and wires of which are free from sparking, are to be used when fuel tanks are open for examination and cleaning or when taking in fuel. As soon as the tanks are filled they are to be closed and the caps are to be screwed well home, and if any fuel is spilt it is to be cleaned up at once. (*See* clause 3.)

Before fuel tanks are opened for either taking in or discharging fuel, any requisite electrical connections on the switchboard are to be "made," and the engines are to be stopped and properly switched off.

Causes of fire which have occurred have been attributed to a spark, caused by the discharge of high potential electricity, generated by friction in the filling hose during the embarkation of petrol. The accumulation of electricity in the armouring wires of the filling hose can be prevented, by ensuring that these wires are earthed by being in metallic contact with the filling system.

The smell of petrol or paraffin, or any other indication of its presence in a compartment, is a warning of danger, not only from fire, but also from "gassing" by the fumes, and when discovered this should be reported immediately to the Engineer Officer in charge of boats or to the Engineer Officer of the day, and steps should be taken to discover and stop the source of the leakage.

The exhaust from petrol and paraffin engines contains a certain amount of the poisonous gas carbon monoxide. Any leakage of exhaust gases into an enclosed space such as the engine room or cabin is dangerous.

It is difficult for persons who have been in a compartment, such as the engine room, for some time to detect a leak by the sense of smell. Any report of fumes from a person outside the compartment must therefore be treated seriously, and due precautions taken.

All tanks, pipes, carburetters, etc., carrying petrol or paraffin, are to be examined for leakage every morning and evening in harbour, and more frequently at sea, any leakage discovered being reported as soon as possible and also the steps taken to make good the defect.

Any leakage of fuel into the bilges must be thoroughly dried up, and the space well ventilated.

When a motor boat has been stowed with the canvas cover on, all compartments are to be ventilated thoroughly before the engine is started. Floor boards are to be raised as necessary to ventilate the bilges.

(3) *General.*—(*a*) Every possible precaution against explosion must be exercised when opening engines for examination or repair.

(*b*) Waste and dirt of any description must not be allowed to accumulate in a boat, and any clothes or waste used for cleaning bilges or engines are to be burned in the incinerator or disposed of in such a manner as to eliminate risk of fire by accident or spontaneous combustion. (*See* article 91.)

(*c*) Matches are not to be taken into the engine room.

(*d*) If possible it should be assured that sparking from commutators and switches will not take place when the engines are running. On the engines being stopped, magneto and battery switches are to be " broken," and the fuel supply is to be shut off.

(*e*) Tins and casks, etc., containing petrol or paraffin are always to be closed, and they are to be secured in a safe place.

111. How to Extinguish a Fire.—If a fire should occur it is generally a simple matter to put it out, if prompt action is taken before the fire has a chance to spread. A delay of even a minute may allow a small fire to become a serious one. It is essential for the safety of the ship, that everyone onboard should be familiar with the appliances provided, and know how to use them.

A fire can be extinguished either by :—

(*a*) cooling the burning substance below the ignition temperature ;

(*b*) smothering the fire by cutting off the supply of air ;

(*c*) a combination of (*a*) and (*b*).

It is often difficult to locate the exact position of a fire owing to the smoke given off. Smoke can be driven by a finely divided spray of water and special nozzles are provided for this purpose. The Fyrex nozzle will produce either spray or a jet, as required. When the seat of the fire has been discovered it can be attacked by either method.

The best method to employ will depend on the type of fire. The application of water, which is generally available in large quantities, is the best method of dealing with burning wood, coal, and other solids. Water is unsuitable for use on electrical fires, as it will cause short circuits, and care must be exercised in its use on petrol and oil fires, as these liquids float on water. Electrical and oil fires should be smothered by one of the methods given in article 114. Water in the form of a fine spray may be effective in the case of an oil fire and should be used where other means are not available. The best way to extinguish one's clothing, should it catch alight, is to lie down and roll oneself in a blanket or rug.

Whatever the means adopted, steps should be taken where possible to reduce the supply of air to a compartment where a fire has broken out, by stopping fans, closing doors, etc.

112. Firemain System.—In all ships a system of pipes, known as the firemain, extends the whole length of the ship, with branches to hose connections in all the principal compartments, and to various points on the upper deck. A number of pumps, either steam or electrically driven, are provided to deliver sea water to the firemain, and these pumps can also be used for pumping water out of the ship. The pumps in the engine rooms and boiler rooms are known as *fire and bilge pumps*, and those outside as *hull and fire pumps*. Bulkhead or isolating valves are fitted where the firemain passes through the main transverse bulkheads, in order that any length of the firemain which may be damaged can be shut off. In cruisers and larger ships, at least one pump is kept running to maintain a pressure throughout the firemain system. In dry dock the ship's pumps cannot be used, and the firemain is connected by hoses to a fire hydrant on the dock side. In small ships, in which power may not be available when in harbour to run a steam or electrical pump, a hand pump, known as a Downton pump, is fitted. When however two oil-driven electric generators are fitted, an extra electric pump is provided instead of a Downton. A small portable hand pump is being supplied to all small ships. The end of the suction hose of this pump is put over the ship's side.

The number of fire pumps provided depends on the size of the ship. Destroyers have one steam or electrically driven pump, and a Downton pump or small electric pump for harbour use. Battleships have about a dozen fire pumps, some steam and some electric.

In many of the older cruisers and battleships all the fire pumps are not connected to the firemain. It was the common practice for the steam-driven pumps in the engine and boiler rooms, each to have a separate rising main to the main deck, with a hose connection in each compartment through which it passes. These rising mains are not connected to one another, so that each pump can only be used to deal with fires in its own particular section of the ship. The electrically driven pumps which supply the firemain have a capacity of 50 tons per hour, and are hence usually referred to as the 50-ton pumps.

113. Magazine Sprays and Flooding Systems.—In warships special precautions are necessary to guard against ignition of the cordite in the magazines. In cruisers and capital ships, branches are lead from the firemain to a system of spray pipes, fitted over the cordite cases in each magazine. Two valves are fitted on each branch, one at the junction of the branch with the firemain, and a second where the pipe enters the magazine. The first valve is kept locked open, and is only closed when the second valve is worked periodically to ensure that it is in working order. The second valve, which is normally locked shut, can be operated, either from

the cordite handing room just outside the magazine, or from the upper deck. At the upper deck position the wheel for operating the valve is in a locked cabinet. This cabinet must be opened, and a pin in the valve wheel removed, before the valve can be opened from either position. In addition to the magazine sprays, a flooding pipe direct from the sea is fitted to each magazine. To flood a magazine two valves have to be opened, first a seacock, which may supply more than one magazine, and then the flood valve for the magazine to be flooded. The seacocks and flood valves can be worked from the locked cabinets on the upper deck previously referred to, or from a secondary position just above the magazine. It is possible that damage to the ship may cause the operating gear to the upper deck to be jammed. By unlocking and removing a cotter at the lower position, the operating gear to the upper position can be disconnected. The seacocks and flood valves cannot be worked from the lower position, unless this cotter has been removed, or the upper deck cabinet opened and a pin removed from the valve wheel. With the flood valves shut, the seacocks can be opened periodically to ensure that they are in working order, and with the seacock shut, the flood valves can be opened. The small quantity of water that comes through, when carrying out this test, is caught in a bucket. The keys for the magazine flood and spray valves are kept on the magazine key board. It is important that, except in emergency, the magazine flood and spray valve should not be touched, unless the magazine is opened. When the pins in the magazine flooding cabinets or the cotter at the lower positions have been removed, at action stations, or for the periodical test of the valves, the magazine should be inspected to see that no water is coming in, after all pins and cotters have been replaced.

In addition to the cordite magazines, flood valves are also fitted to the small arms and torpedo warhead magazines, fireworks tank, inflammable store, spirit room, and to compartments containing aviation spirit and petrol tanks. These compartments are not however fitted with sprays.

In vessels with small-calibre guns, where each charge of cordite is contained in a brass cartridge case, magazine sprays are not fitted. For many years it was the practice in destroyers to provide for flooding the magazines by a portable connection from the fire-main. This entails working the Downton pump when steam is not available, unless the firemain can be connected to a shore fire hydrant. In the latest destroyers magazine floods from the sea are fitted.

114. Oil and Petrol Fires.—There is always a danger of spreading oil or petrol fires by the application of water. If, however, other means are not available water should be used, but only in the form

of spray. A fine spray falling on burning oil in sufficient quantity forms on the surface a mixture of oil and water which does not readily burn.

The following methods, although especially applicable to oil fires, are also effective in the case of other fires. Chemical fire extinguishers are particularly suitable for electrical fires.

(1) *Canvas.*—Covering the fire with a piece of canvas or other material, preferably damp.

(2) *Sand or earth.*—Covering a burning liquid with sand or earth, both cuts off the air, and cools the liquid below the ignition point.

(3) *Chemical extinguishers.*—By spraying on to a fire a liquid which gives off a heavy incombustible vapour, the air supply can be cut off, and also the heat absorbed by the vaporisation of the liquid reduces the temperature of the burning substance. The liquid is put up in portable containers, from which it is ejected either by a hand pump or by a small quantity of gas under pressure above the liquid. The type of chemical fire extinguisher most commonly supplied to H.M. ships is the Pyrene, but the Essex Methyl-bromide extinguisher is fitted in the larger motor boats. A description of these extinguishers is given in articles 117 and 118.

(4) *Foam.*—A foam will float on oil or petrol, and if correctly applied will shut off the air from burning oil, and so extinguish the fire. The foam should be directed on to the edge of the fire nearest the operator, and caused to flow across the fire. The foam will adhere to any surface, even vertical bulkheads, and is suitable therefore for any sort of fire.

There are three methods of making the foam :—

(*a*) *Foam-type fire extinguisher*, in which the foam is formed by the mixing of two solutions in a portable container. Carbon dioxide gas is generated by a chemical action between the two solutions. This gas, together with the liquid of the solutions, forms the foam, and the pressure generated in the container causes the foam to be ejected through a nozzle fitted on the container, or through a short length of hose attached to the container. This portable type is provided for use in motor boats, and in the boiler rooms of ships with oil-fired boilers. A detailed description is given in article 119.

(*b*) *Continuous foam generator*, where water from the fire-main is passed through a generator containing a foam-forming compound in the form of powder. The foam is directed on to the fire through a hose attached to the outlet side of the generator. Each unit consists of two generating chambers with the necessary valves, so that one may be recharged while the other is in use. Continuous foam generators are only fitted

on the flight decks of aircraft carriers, and adjacent to the catapults of other ships carrying aircraft. (*See* article 120.)

(*c*) *Foam-making branch pipe.*—In this new method of producing foam in large quantities, a liquid foam-making compound is forced into the firemain adjacent to selected hose connections. Liquid foam-making compound gives better results than foam-making powder in cold climates. The liquid is placed in a small tank adjacent to a branch off the firemain. Each tank is divided into two compartments, one of which can be open for recharging while the other is in use. Water from the firemain is admitted to the top of the compartment in use, and the liquid in this compartment is thus caused to flow into the branch from the firemain, where a mixture of foam-making liquid and sea water is formed. The liquid does not form foam with water until air is admitted to the mixture, and this is drawn in at the base of the special foam-making branch pipe.

(5) *Steam.*—The use of steam for extinguishing an oil fire in a boiler room is described in article 69.

115. Electrical Fires.—This type of fire is best dealt with by means of a chemical fire extinguisher, as the liquids used in these extinguishers are poor conductors of electricity. The current should be switched off as quickly as possible. If a chemical fire extinguisher is not available, or is not effective, foam should be used in preference to water. Neither foam nor water should be applied until the current has been switched off, or the operator may receive a severe shock.

116. Chemical Fire Extinguishers. Precautions.—The vapours of the liquids used in these extinguishers are toxic, and although the makers claim that it is safe to remain in a compartment in which a sufficient quantity of the liquid has been released to extinguish a fire, one fatal accident has occurred through a man working in the engine room of a motor boat in which one of these extinguishers had been used. In the open a chemical fire extinguisher should be used from the windward side, and when the fire is in an enclosed, or partially enclosed space, the operator should if possible stand outside the space, and operate the extinguisher through a doorway. If it is necessary to enter a compartment in which there is a fire, or in which there has recently been a fire and the compartment has not since been well ventilated, either a pattern 230 or a Salvus breathing apparatus must be worn. The service respirator will afford protection against the vapours from a chemical extinguisher, but the fire may have used up most of the oxygen from the air in the compartment, and it is possible that

carbon monoxide may be present, in which case a respirator will afford no protection.

The liquid used in methyl-bromide extinguishers will cause blisters; such blisters may not appear until several hours after contact. Damaged or leaky extinguishers must be discharged in the open, and care must be taken to avoid contact with the liquid. If the skin or clothing should become contaminated with the liquid, medical aid should be sought as soon as possible.

117. Pyrene Fire Extinguisher.—This type of extinguisher is supplied in two sizes, namely one quart and two gallon, and is filled with specially treated carbon tetrachloride, known as Pyrene liquid. In each extinguisher is incorporated a double-acting pump, by means of which the liquid can be discharged to a distance of 25 to 30 feet.

In the quart size extinguisher the liquid is discharged through a nozzle at the opposite end of the container to the pump handle. The container is held in one hand and the pump worked with the other. The pump is so designed that it will take its suction from the lowest part of the container, no matter at what angle the extinguisher is held. When the handle is pushed in it can be locked, by turning it through a quarter of a turn. In this position the discharge tube, which extends the whole length of the container inside the pump rod, is sealed by a cork inside the handle. A second cork washer in the handle seals the pump rod gland. These cork washers prevent evaporation or the escape of liquid. When the extinguisher has been in use the nozzle tube will be full of liquid; this should be shaken out before refilling the extinguisher and replacing it on its bracket. A hole with a screwed plug is fitted for recharging

The two-gallon size stands on a flat base, with the pump handle and the discharge nozzle at the top. A short length of rubber hose is attached to the discharge nozzle, to enable the liquid to be discharged in any direction. This extinguisher functions most efficiently, with one man to work the pump, and another to direct the jet from the hose.

Upkeep and Tests.—The parts round the handle, locking plate and filter cap, must be kept clean. Water and metal polish should not be used for this purpose, a rag moistened with Pyrene liquid can be used if necessary. If the nozzle is obstructed, it should be cleared with a piece of wire.

Pyrene extinguishers are to be tested in the open air, on receipt from store, and once every quarter, to ascertain that the passages for the discharge of liquid are clear, and that the pump is in good working order.

To test a quart-size Pyrene, place a finger over the nozzle,

unlock the pump by turning the handle, give one double stroke and relock. The pump should work freely and on shaking the extinguisher a few drops of liquid should come from the discharge tube.

The two-gallon size is tested by pumping through the hose and back into the container through the filling aperture. After testing the hose should be drained.

Pyrene extinguishers can be recharged by ship's staff, by pouring in Pyrene liquid through the filling holes. The liquid is supplied in one-quart and in one-gallon tins. Extinguishers should be recharged immediately after use, and topped up after the quarterly test and when drawn from store.

Serviceable extinguishers must be topped up before being returned to store on paying off. Re-charging and topping up of Pyrene extinguishers must always be done in the open air. Defective extinguishers returned for survey should not be topped up, and should be accompanied by a report stating the code number stamped on the handle, whether full or empty and whether pump is free.

118. The Essex Featherspray Fire Extinguisher.—This type of extinguisher is fitted in large petrol-engined motor boats. These extinguishers are charged with methyl bromide, which like carbon tetrachloride gives off a heavy incombustible vapour, which is most effective in smothering a petrol or electrical fire. The boiling point of methyl bromide is below normal atmospheric temperature, and so it cannot be pumped from the container. In addition to the liquid methyl bromide, the extinguisher contains a charge of nitrogen gas under a pressure of 50 lb. per square inch. After charging, the container is sealed with a copper disc. Over this is screwed a cap containing the nozzle, and a device for puncturing the copper disc. The extinguisher must be held vertical when in use, with the outlet at the bottom, in order that all the liquid shall be expelled by the expansion of the gas.

The Featherspray equipment comprises two or three extinguishers, each held by spring clips in a bracket incorporating a pipe line and a lever. The pipes from the brackets lead to the engine and to the space containing the petrol tank. Pulling the lever operates the spindle which punctures the copper disc, and allows the liquid to be discharged through the pipes. The extinguishers can be removed from the spring clips and used in another part of the boat if required. The disc can be punctured by bumping the flat disc at the bottom of the extinguisher on to the deck. Unless great care is taken the disc will be punctured in removing the extinguisher from the clips. Once the disc is punctured the flow of liquid cannot be stopped until the extinguisher is empty.

These extinguishers have to be returned to the makers for re-charging.

119. Two-Gallon Foam-Type Extinguishers.—Fig. 22 shows a section through a portable 2-gallon foam-type extinguisher. This type is known as Dual Seal. In normal temperatures this extinguisher will produce 16 to 18 gallons of foam. The jet of foam is thrown 20 to 30 feet and no noxious fumes are produced. In cold weather the extinguisher should be stored in a position where the temperature is not likely to fall below 40° F.

The acid solution is sealed in the inner container by valve D, and the outer container is closed by valve B. To operate the extinguisher turn the " T " handle at the top until the locking sleeve is freed from the bayonet point. When the locking sleeve is free it will be lifted by a spring and valves B and D will be opened. Next invert the extinguisher to allow the two solutions to mix. Foam will now be discharged through the nozzle. The extinguisher must be held vertical with the nozzle at the bottom until it is empty.

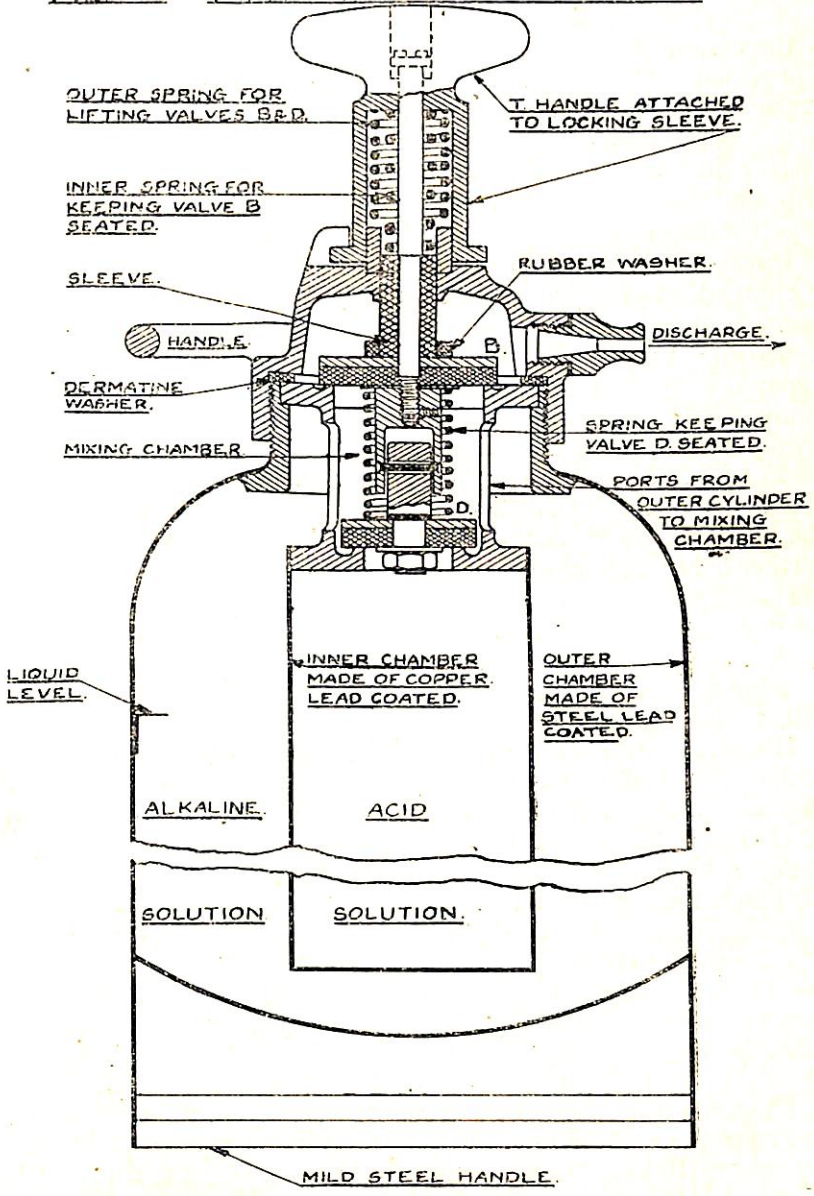
Charging.—On issue from store or after use the extinguisher must be charged. Having released the " T " handle the top can be screwed off and the inner container lifted out. The inner and outer containers and the head should be rinsed with fresh water. The powders for preparing the solutions are supplied in tins, No. 1 tin (yellow label) containing a charge for the outer container and No. 2 tin (blue label) a charge for the inner container. The tins containing the powder are used to measure out the quantity of water required. For No. 1 solution use seven of No. 1 tins full of fresh water, and for No. 2 solution one of No. 2 tin. The powders take some time to dissolve in cold water. If possible use water at about 100° F. for No. 1 solution and boiling water for No. 2. The No. 1 solution should fill the outer container to the projecting ledge. Fresh water should be added if necessary to bring solution to this level before replacing inner container. The level of the liquid in the inner container should be half an inch below the valve seat. Having filled and replaced inner container, screw on top and close valves by depressing and locking " T " handle.

Testing.—The solutions in all Dual seal extinguishers should be tested every six months. Five cubic centimetres of the solution from the inner container and twenty-five cubic centimetres of the solution from the outer container are poured together into a half-pint measure. If the resulting foam is less than three-eighths of a pint the extinguisher must be re-charged with fresh solutions.

When a charge has been in a foam type extinguisher for two years it should be discharged, thoroughly cleaned and examined for corrosion. If corrosion is found the extinguisher must be tested by water pressure to 350 lb. per square inch. The extinguisher

must be tested by water pressure after repair, and also when an interval of four years has elapsed since previous test. A tally plate on the extinguisher shows the date of last water pressure test, when last filled, and when solutions were last tested.

FIG:-22. "FOAM TYPE" FIRE EXTINGUISHER.



When old charges are expended, opportunity is to be taken to instruct ship's companies in the use of these appliances. Practice should occasionally be given in extinguishing a specially prepared fire made in some safe place on shore. Oil and waste in a tray about 3 ft. square will form a suitable fire.

120. Continuous Foam Generators.—*Type 77 Phomene Generator* consists of two vertical cylinders, in which the foam is generated by the action of jets of water on Phomene powder. Each cylinder is provided with a cover for charging, a water inlet valve, a non-return outlet valve, a drain valve and a pressure gauge. The charges are supplied in airtight containers. The container is inserted in the generating chamber, after tearing off the sealing strip and removing the lid. The powder deteriorates if allowed to absorb moisture.

During flying operations only one cylinder in each pair should be charged, and the chamber should be dry, to avoid spoiling the charge if the generator is not used. If the generator contains an opened and unused charge, left since the last time generator was prepared, any incrustation on the top of the charge should be removed. If the powder remaining is in good condition, 5 ozs. of powder stirred with $2\frac{1}{2}$ pints of salt water at a temperature of 60° F. will give at least $1\frac{1}{2}$ gallons of foam. If the powder is caked to a depth of more than 2 inches the charge should be discarded. The hoses should be connected and the drains on cylinders closed. Further charges should be available, but they should not be opened unless required. The generators are designed to operate with a water pressure of 25 to 30 lb. per square inch. When standing by during flying operations, the arrangements should be such that the above working pressure is available and can be maintained while the generator is operating.

If water is turned onto the loaded cylinder, foam is immediately produced and the pressure generated in the cylinder forces the foam out through the discharge hose. After about two minutes the charge will be used up and the second cylinder must be brought into operation.

If a charge is opened and not used the date it was opened should be marked on it. The opened charge should be left in the generator with the inlet valve tightly closed and the drain shut. All opened tins of powder should be examined and tested as previously described every two months. Charges which have been opened for six months should be utilised for practice and not regarded as suitable for fire risk.

The generator should be examined for corrosion after use. If serious corrosion is found the generator is to be tested by water pressure to 100 lb. per square inch. In any case a pressure test

must be carried out once every four years, and the date of the test stamped on the metal label attached. Generators are to be discharged before return to store. The hoses are to be examined, and tested on the firemain once a quarter.

Pyrene Foam Making Equipment.—This type of continuous foam equipment is being introduced in place of Type 77 Phomene generators. A liquid foam making compound is used in conjunction with a foam making branch pipe. (*See* article 114 (4) *c.*)

121. Soda-Acid and Nuswift Fire Extinguishers.—Soda-acid extinguishers are not supplied to ships, but will be found in some shore establishments. They will throw a small jet of water a distance of 30 to 35 feet. By inverting the extinguisher, or by striking a knob which breaks a bottle in the container, acid is allowed to flow into the water in the container. The water contains bicarbonate of soda in solution. Carbon dioxide gas is generated, and the pressure of the gas forces the water out through the nozzle.

The Nuswift extinguisher, which is now being introduced, consists of an outer vessel containing about two gallons of water and a small gas cylinder, containing CO_2 gas under pressure, fitted in the upper portion of the outer vessel. Striking a knob on top of the extinguisher punctures the gas cylinder and allows the gas to pass into the outer vessel above the water, which is thus forced out through a nozzle. A fitting is provided on the nozzle which enables the water to be directed on to the fire as a jet or as a fine spray. Spare gas cylinders are supplied with each extinguisher for recharging.

CHAPTER VIII.

THE STEAM RECIPROCATING ENGINE.

122. Principle and Development of the Steam Reciprocating Engine.—In a reciprocating engine the difference in pressure on two sides of a piston, which is a good fit in a cylinder, causes this piston to move from one end of the cylinder to the other. The movement of the piston can be caused to actuate the plunger of a pump as in Fig. 25, or to rotate a crank as in Fig. 23. In the first steam engine steam was admitted only to one end of the cylinder, and when the piston reached the other end the steam was condensed, either by admitting a jet of cold water into the cylinder or by allowing the steam to flow into a separate vessel, known as a condenser, in which it was condensed. The condensation of the steam caused a vacuum to be produced in the cylinder on the steam side of the piston, and the atmospheric pressure on the other side returned the piston to the starting point.

The first steam engine was built in England by Newcomen in 1712. Watt introduced the condenser and made other improvements which materially increased the efficiency of the steam engine. The steam pressure used in Newcomen's and Watt's engines was only a few pounds above atmospheric pressure, and the engines were single-acting, that is, steam was only used on one side of the piston. These early engines were used for pumping out mines, and they were very large and cumbersome for the amount of work they performed.

Increase in the steam pressure employed, and the introduction of the *double-acting engine*, in which steam is admitted in turn to each side of the piston, materially reduced the size of steam engines. With higher steam pressures, not only was more power obtained from the same size cylinder, but it was possible to effect an economy by shutting off the supply of steam before the piston reached the end of the stroke, and completing the stroke by the expansion of the steam in the cylinder.

A further improvement was made by the introduction of the *compound engine*, in which the high-pressure steam is admitted and partially expanded in one cylinder, known as the high-pressure or H.P. cylinder, and then passes to a larger cylinder, known as the low-pressure or L.P. cylinder, in which the expansion is completed.

It was towards the end of the eighteenth century that steam engines were first used to propel boats, but it was not until the introduction of the compound engine, about the middle of the

nineteenth century, that the steam engine became a serious rival to sail. By this time steam pressures of 60 lb. per square inch were employed.

Further increase in steam pressure led to the introduction of the *triple-expansion engine*, in which the steam exhausted from the H.P. cylinder passes, first to an intermediate or M.P. cylinder, and then to one or two L.P. cylinders in which the expansion of the steam is completed. When steam is expanded to a lower pressure its volume increases. The M.P. cylinder must be a larger diameter than the H.P. to receive the same amount of steam at a lower pressure, and similarly the L.P. cylinder must be larger than the M.P. For the sake of economy it is desirable to expand the steam to as low a pressure as possible before exhausting it to the condenser. Large triple-expansion engines generally have two L.P. cylinders, each designed to take half the exhaust from the M.P. cylinder. In this way the necessity for a very large L.P. cylinder is avoided; such a cylinder would be unwieldy and difficult to manufacture.

123. Parts of Reciprocating Engine.—The names of the various parts of a reciprocating engine are shown in Fig. 23. The *cylinder* is an iron casting bored out internally to form a true cylindrical chamber in which the piston works. In large engines, instead of forming the smooth cylindrical surface in the cylinder casting itself, a machined cylindrical *liner* is fitted in each cylinder, and the piston works in this liner. A cover is fitted at the top end of the cylinder, large enough to enter the piston into the cylinder. In the bottom, which is part of the cylinder casting, is a hole for the piston rod. This hole is shaped to form *a stuffing box*, in which packing is placed to prevent steam leaking from the cylinder. The packing is held in place by a *gland*. The cylinder is supported by columns from the engine *bedplate*, which carries the *main bearings* in which the crankshaft revolves.

The *piston* is an iron or steel casting, made slightly smaller in diameter than the cylinder or liner in which it works. To prevent steam leaking past the piston one or more rings are fitted in the piston. These *piston rings* are usually cut through at one point in the circumference, so that they spring out to fit the cylinder. The piston shown is provided with a *junk ring*, to allow for the removal and replacement of the piston ring. When a number of light rings are fitted instead of one heavy ring, a junk ring is not essential, as the rings can be sprung out sufficiently to insert them in grooves turned in the solid piston.

The *piston rod* is a steel forging, secured to the piston at one end, and at the other end having a *slipper* which works in a *guide*, to keep the lower end of the rod in line with the cylinder.

The *connecting rod*, which is also of forged steel, is connected

to the lower end of the piston rod by the *crosshead bearing*, and to the crankpin by the *crankhead bearing*.

Formed in the cylinder casting is another chamber known as the *slide valve chest*. There is a passage or port from the slide valve chest to each end of the cylinder. There is a connection on the

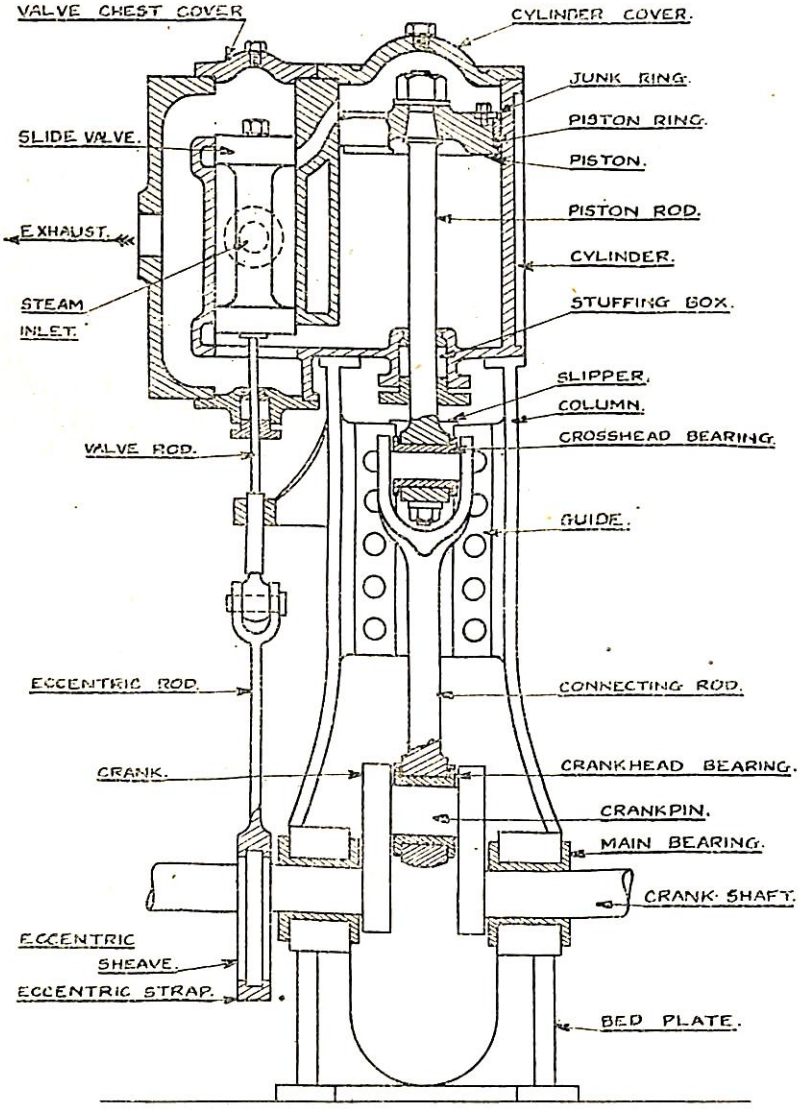


FIG:-23. RECIPROCATING ENGINE.

slide valve chest for the admission of high pressure or live steam to the engine, and another connection through which the exhaust steam can pass away after it has done its work in the cylinder.

The *slide valve* moves up and down in the slide valve chest, and thus admits steam to each end of the cylinder in turn, and at the same time putting the other end in connection with the exhaust orifice. In Fig. 23 the engine is shown on the top dead centre, that is, the piston is at the top end of its stroke. The slide valve is moving up, thus admitting steam to the top of the cylinder and opening the bottom of the cylinder to exhaust. The slide valve shown is cylindrical in form. Such valves are often called piston valves, to distinguish them from the D-shaped valves which are now only fitted for the L.P. cylinders of triple-expansion engines. The slide valve is carried on a *slide valve rod* which is attached to the top end of the *eccentric rod*. The bottom of the eccentric rod is bolted to the *eccentric strap*, which encircles the *eccentric sheave* on the crankshaft. Due to the eccentricity of this sheave, rotation of the crankshaft causes the slide valve to move up and down.

124. Starting a Reciprocating Engine.—In certain positions of the slide valve steam is not open to either end of the cylinder. To start a single-cylinder engine, it must be turned by means of the turning gear, until it is just over the top dead centre in the direction of rotation, in which position the steam port to the top of the cylinder will be partly open. Then, if the engine has been thoroughly warmed and all water drained from the cylinder and slide chest, through the drain cocks fitted for its purpose, it should start on opening the exhaust valve wide, and easing off the steam valve. On no account must a steam reciprocating engine be started until it is warm and well drained, as if there is any appreciable quantity of water in the cylinder when the piston reaches the end of its stroke a considerable amount of damage may be done.

In the case of triple-expansion main engines it would not be possible to turn the engine into a starting position each time it is stopped. On the main engines a little live steam can be admitted to the M.P. or L.P. cylinder to move the engine, should it stop in such a position that the port from the slide valve chest to the H.P. cylinder is covered by the valve. *The turning gear fitted to main engines must be disconnected before steam is put on the engine.*

125. Stephenson's Link Motion.—Since it is necessary that the main engines shall be capable of propelling the ship either ahead or astern, provision is made so that the main engines can be revolved in either direction. Two eccentrics and eccentric rods are provided for each slide valve. The top ends of each pair of eccentric rods are connected to a *link*, and the bottom end of the slide valve rod is attached to a link block free to slide in the link. By movement

of the link either eccentric rod can be brought in line with the slide valve rod. With one of each pair of eccentrics operating the slide valve, the crankshaft will revolve in the ahead direction, while with the other eccentric in use the crankshaft will revolve in the astern direction. Each link of a triple-expansion engine is connected by a drag link to an arm on a *weigh shaft*, so that by movement of this shaft all the links are moved together. The weigh shaft is moved by hand in small engines, and in large engines by a small steam *reversing engine*. When the engines are stopped the link should be put in the mid position.

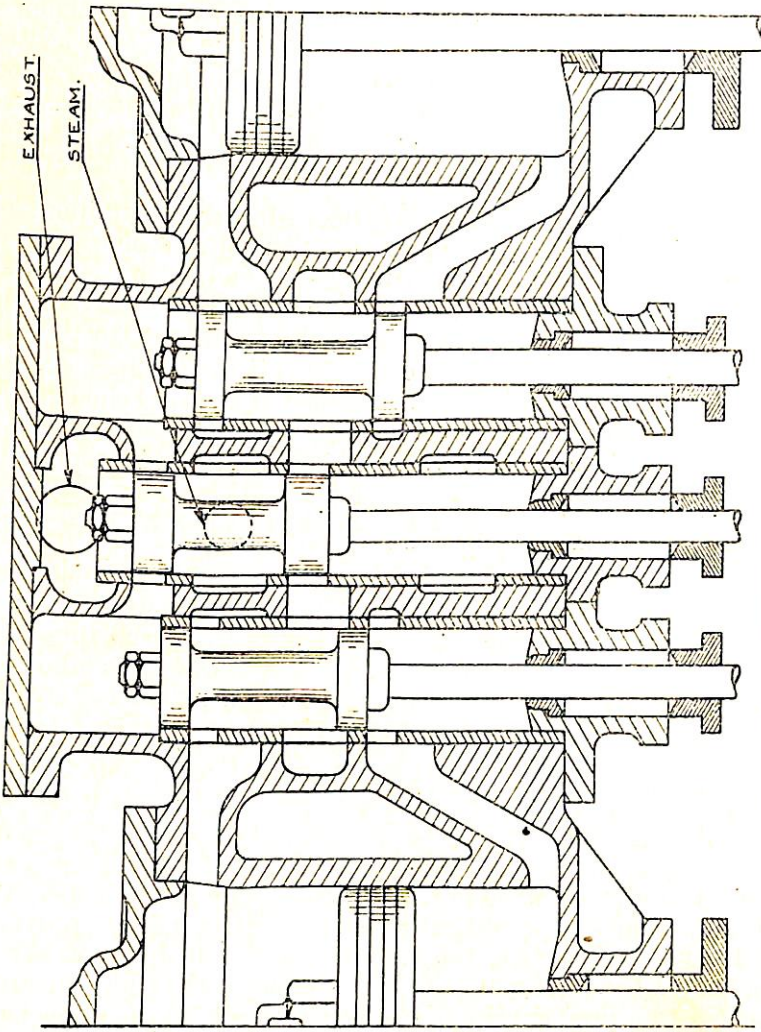


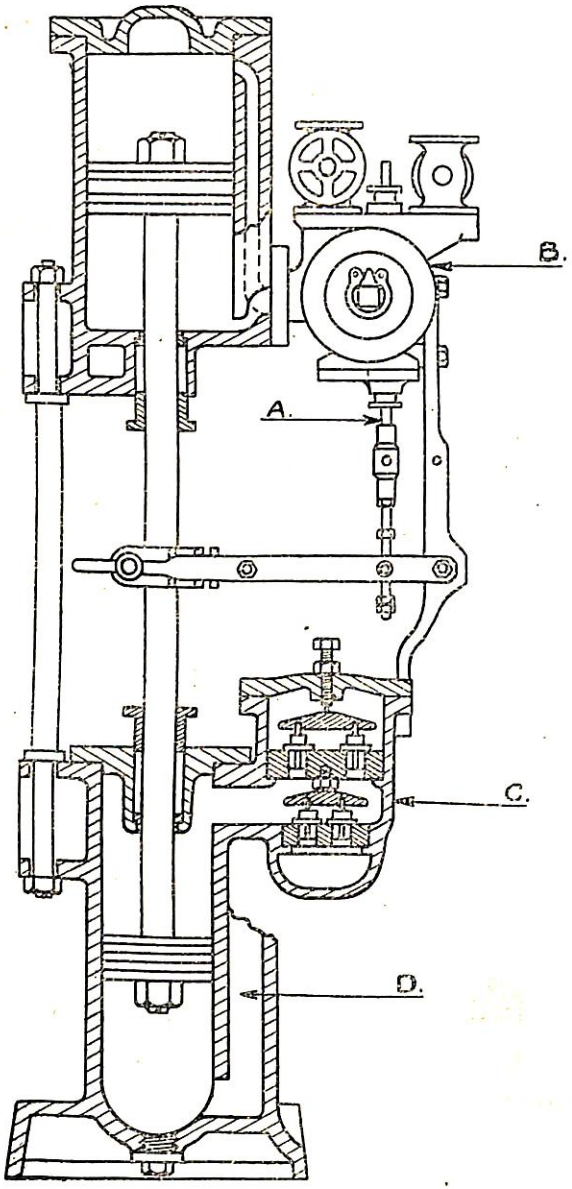
FIG:-24. DIFFERENTIAL VALVE.

126. Differential Valve.—The capstan engine and steering engine must also be reversible. For these engines a differential valve is employed. The engines are two-cylinder simple engines, and the cranks are arranged at an angle of 90 degrees, to ensure that the engine will start from any position in which it might happen to stop. There is one slide valve to each cylinder, and between these is the differential valve, which is operated from the bridge in the case of the steering engine, and from the forecastle in the case of the capstan engine. A passage connects the space above each slide valve to the space below the valve as in Fig. 23; another passage connects the space above the differential valve to the space below this valve. In Fig. 24 the differential valve is shown in the mid position, the right-hand piston is on the top dead centre, and the left-hand piston at mid stroke. The ports to the slide valve chests are closed by the differential valve, and the engine will be stopped. If the differential valve is moved downwards, the centre of the slide valves will receive steam, and the top and bottom of each slide valve will be in communication with the exhaust. The left-hand piston will move down, and the engine will continue running in this direction until the differential valve is again brought to the mid position. If the differential valve is moved up, the centre of the slide valves will be put to exhaust and the outside to steam, and the engine will run in the opposite direction.

127. Direct Acting Pumps.—In these pumps the slide valve is operated by a system of levers and links from the bottom of the piston rod. Different arrangements have been adopted by different makers. Fig. 25 shows a Weir's pump, which is the most common make in H.M. ships. The slide rod A carries an auxiliary valve which works on a flat face on the main slide valve, or shuttle, in the valve chest B. The shuttle has a cap on each end forming a small cylinder. The shuttle is moved backwards and forwards in this cylinder by the admission of steam to one end of the shuttle and the opening of the other end to exhaust. The steam to operate the shuttle passes through small ports on the flat face of the shuttle on which the auxiliary valve works. With the pump on the upstroke the shuttle is over to the right. As the pump approaches the end of the stroke the auxiliary valve uncovers ports, admitting steam to the right-hand end of the shuttle and putting the left-hand end in communication with exhaust. This causes the shuttle to be thrown across to the left, so opening steam to the top of the pump cylinder and the bottom to exhaust. The shuttle caps can be turned through a small angle by means of spindles projecting through the ends of the shuttle chest. If these spindles are turned until a pointer on the spindle is against a stop marked "S," the supply

of steam will be shut off from the pump cylinder at about three-quarter stroke, by the auxiliary valve closing a port on the face of the shuttle. The stroke of the pump is then completed by the

FIG:-25 WEIRS PUMP.



expansion of the steam in the cylinder. By turning the shuttle caps so that the pointers are against the stops marked " O," a notch in the cap is brought into line with a port on the shuttle, and the pump receives steam for the whole of its stroke. The pointer on the left-hand side of the shuttle chest is arranged to point upwards to denote that it affects the up stroke of the pump, while the pointer on the right-hand side points down and affects the down stroke. When starting a Weir's pump both pointers should be at " O." When the pump is thoroughly warm, putting the pointers to " S " will cause the pump to run more quietly and more economically. A special spanner is provided, one end of which can be used to turn the shuttle caps, and the other end to move the auxiliary valve to ascertain that it is free, if difficulty is experienced in starting the pump.

Provision is made for lubricating the shuttle by fitting a permeator on the valve chest. If the shuttle is taken out after the pump has been used, and given a thin smear of heavy oil, it will not be necessary to use the permeator when the pump is running. *Oil should only be introduced through the permeator when orders are received to do so, as the excessive use of these fittings may cause damage to the boilers.* (*See* articles 15 and 20.)

When a pump is stopped, unless the turning gear is put in, the piston and plunger will gradually sink to the bottom. If pumps are always stopped on the up stroke the shuttle will be in the position where steam is admitted to the bottom of the cylinder on opening the steam valve.

The pump shown in Fig. 25 is a feed pump. The water end of the pump is also double acting. The pump valve chest containing the suction and delivery valves for the top half of the pump is shown in section at C. The passage D communicates with a similar set of suction and discharge valves for the lower half of the pump.

CHAPTER IX.

STEAM TURBINES.

128. Action of the Steam in a Turbine.—If there is a hole in a vessel containing high-pressure steam, a jet of steam will issue from this hole with considerable velocity. An increase in the velocity of this jet of steam can be obtained, by allowing the steam to escape through a specially shaped aperture, known as a *nozzle*. The velocity attained by the jet of steam will depend on the difference in pressure of the steam in the vessel, and in the space into which the steam is escaping. If steam be expanded from 250 lb. per square inch to condenser pressure through a suitable shaped nozzle, it will attain a velocity of over 4,000 feet per second. This is about twice the velocity at which a bullet leaves a rifle.

If a jet of steam be directed on to a vane, placed at such an angle that the direction of flow of steam be changed, then a force or impulse will be exerted on this vane. There will also be a force exerted on the vessel from which the steam is escaping. This force, which is called a reaction, will act in the opposite direction to that in which the steam is travelling. (The reaction to the force exerted on the bullet, when a rifle is fired, is felt by the person holding the rifle.)

In a turbine, suitable vanes or blades are arranged on a drum or wheel, which is free to revolve inside a casing. A flow of steam is arranged to pass through these blades, in such a manner, that a force is exerted on the blades, thus causing the drum or wheel to rotate. In addition to the blades on the drum or rotor, there are generally rows of blades in the casing. These fixed blades are arranged to redirect the steam after it has passed through a moving row of blades, in order that a force may be exerted in the right direction on a further row of moving blades.

If the expansion of the steam takes place entirely in fixed nozzles, and there is no drop in pressure as the steam passes through the blades, the turbine is known as an *impulse turbine*. If the blades are so designed that there is a drop in steam pressure between the inlet and outlet side of each row of blades, and a consequent increase in the velocity of the steam relative to the blades as it passes through each row, there will be a reaction on the blades, and the turbine is known as a *reaction turbine*.

Except in the case of the small turbines used for auxiliary machinery, the expansion of the steam from boiler pressure to condenser pressure is not carried out in one turbine. For normal boiler pressures, that is up to about 300 lb. per square inch, the steam is ex-

panded from the initial pressure down to about 25 lb. per square inch in an H.P. turbine, and then exhausted to an L.P. turbine, in which the expansion is completed. For higher boiler pressures, one or more intermediate-pressure turbines are fitted, through which the steam flows between the H.P. and L.P. turbines.

A turbine, designed to rotate a shaft in one direction cannot be used to turn the shaft in the opposite direction. When turbines are used for the propulsion of ships, separate turbines are provided for going astern. The astern turbines revolve idly when the ship is steaming ahead. They are designed to give the necessary astern power with the minimum weight, and are not economical in steam consumption. The maximum revolutions astern, with all boilers in use, is only about two-thirds of the maximum revolutions when going ahead.

129. History of the Steam Turbine.—The first successful steam turbine was designed in 1884 by Sir Charles Parsons, to drive an electric generator. Thirteen years later, an experimental steam boat, fitted with Parson's turbine, was built. This vessel, which was named the *Turbinia*, achieved a speed of 34½ knots, about 4 knots faster than the fastest destroyer of that time. The turbines of the *Turbinia* were coupled direct to the propeller shafts. They ran at a lower speed and were larger than a modern set of geared turbines of the same power. Nevertheless, it was evident that, compared with reciprocating machinery, the turbine would give more power for same weight of machinery, and the machinery being placed lower in the vessel, was less liable to damage by gunfire.

In 1901, two destroyers were fitted with Parson's turbines, and in 1906, H.M.S. *Dreadnought*, the first turbine-driven battleship, was completed. These turbines were direct drive, as in the *Turbinia*. During the last ten years of the nineteenth century, a number of other turbines were developed in foreign countries. The Curtis turbine, patented by an American in 1896, has been fitted in many American ships, and developed in this country under the name Brown Curtis. A few British Naval vessels have been fitted with Brown Curtis turbines.

In the early turbine-driven vessels, all the auxiliary machinery was driven by small reciprocating engines. Small turbines have since been introduced, first for one type of auxiliary, and then for another. In the latest ships, all the auxiliaries are turbine driven, except a few which are driven by electric motors.

130. Single-stage Impulse Turbine.—Fig. 26 shows a simple form of impulse turbine, such as is used to drive a fan or other small auxiliary engine. In this turbine the steam is expanded in one stage, from the receiver pressure to the exhaust pressure. The

velocity of the steam is very high, and the turbine must run at high speed to achieve reasonable economy.

The wheel A is made of forged steel, and is about 1 foot in diameter. It is shrunk and secured on to a steel spindle, which is

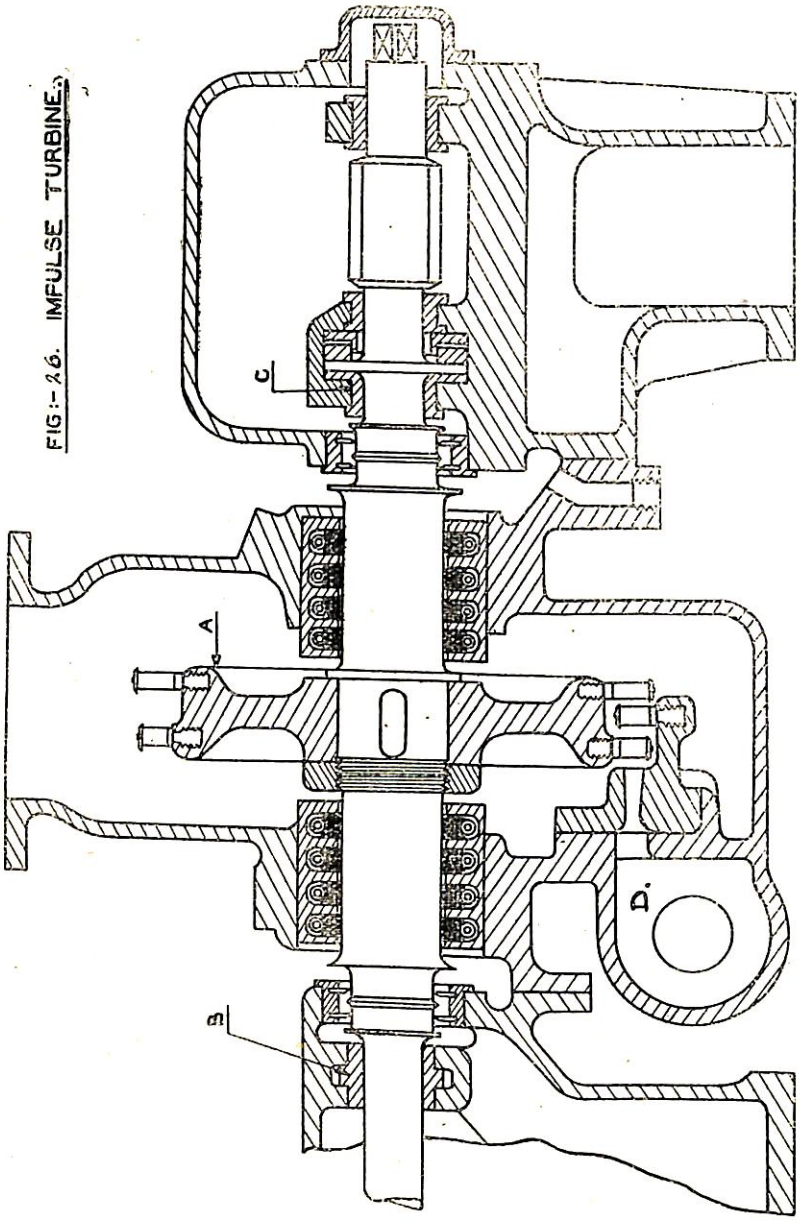


FIG:- 26. IMPULSE TURBINE.

free to revolve in the main bearings B and C. In the bearing C is incorporated a thrust bearing, which keeps the spindle and wheel in the correct axial position.

On the circumference of the wheel are two rows of stainless steel blades, with their roots firmly fixed in grooves turned in the wheel. To give additional support to the blades, a strip of metal, known as the *shrouding*, is fitted in short lengths round the tips of the blades. A spigot, at the end of each blade, passes through a hole in the shrouding, and is riveted over.

Surrounding the wheel is the turbine casing or cylinder, which is in two halves bolted together. The upper half of the casing is of cast iron, but the lower half is made of cast steel, as it contains the nozzle box D, which has to withstand the pressure and temperature of the steam before expansion.

A *gland* is fitted on each side of the wheel, where the spindle passes through the casing, to prevent leakage of steam. This gland consists of a bronze bush, which is in two halves and has four internal grooves. In each groove is fitted a carbon ring in three segments. A garter spring keeps the segments together and pressed on to the spindle. A drain is fitted to each gland. These drains should be kept open when the turbine is not running, to avoid an accumulation of water in the gland and rusting of the turbine spindle.

Steam is admitted to the nozzle box through the steam valve of the turbine. Leading from the nozzle box to the inside of the casing are a number of holes or nozzle passages, arranged in the arc of a circle. The expansion of the high-pressure steam, from the nozzle box to the low pressure in the casing, causes the steam to issue from the nozzles with considerable velocity. The jets of steam from the nozzles impinge on the blades at such an angle that the wheel is caused to rotate. In passing through the first row of blades the velocity of the steam is reduced, and also the direction in which the steam is moving is changed. The steam now passes between a number of fixed blades which change the direction of flow, so that the steam exerts a force in the right direction on the second row of moving blades. These fixed blades only extend over an arc corresponding to the arc covered by the nozzles.

The turbine shown in Fig. 26 is designed to run at 10,000 revs. per minute, with a pressure of 225 lb. per sq. in. in the nozzle box and a pressure of 25 lb. per sq. in. in the turbine casing. When not required to run at full speed, the pressure in the nozzle box may be reduced, by partially closing the steam-regulating valve. It is more economical at low speeds to shut off some of the nozzles, and maintain a high pressure in the nozzle box. In many turbines the nozzle box is divided into two or more sections, with a separate valve to control the steam to each section.

131. Multi-Stage Impulse Turbine.—The single-stage impulse turbine, described in the previous article is not designed to expand the steam to condenser pressure. Also, as further use is made of the steam exhausted from such a turbine, simplicity and lightness are of greater importance than economy of steam consumption. Where an impulse turbine is to exhaust direct to a condenser, and it is therefore desirable to achieve maximum economy, it is usual to fit what is known as a multi-stage turbine. Such a turbine consists of a number of single-stage impulse turbines in series, enclosed in a single casing in the case of the small turbines required for auxiliary machinery. A number of wheels are mounted on the spindle, each wheel carrying one or more rows of blades. The casing is divided internally into a number of separate chambers or stages by circular *diaphragms*. The outer circumference of each diaphragm fits in a groove turned in the inside of the casing, and there is a hole in the centre of the diaphragm through which the spindle passes. To prevent leakage of the steam from one stage of the turbine to the next, where the spindle passes through the diaphragm, packing rings are fitted in the hole in the diaphragm. These packing rings have a number of knife edges which almost touch the spindle. In each diaphragm are a set of nozzle passages, through which the steam, exhausted from one stage, is expanded, and its velocity increased before impinging on the blades in the next stage. The reduction in the velocity of the steam, as it passes through the blades on each wheel, is restored in the next set of nozzles.

By the adoption of a number of stages, with partial expansion in each stage, expansion to condenser pressure can be achieved, without unduly high steam velocities. Also, with lower steam velocities, lower blade velocities can be employed, and there will be no necessity for the turbine to be designed to run at such high speed to obtain economical results.

132. Brown Curtis Turbine.—This is a multi-stage impulse turbine. As previously mentioned, it was introduced as a rival to the Parson's turbine for the propulsion of ships. As with the early Parson's turbines, the first Brown Curtis turbines fitted were direct drive. For destroyers two independent turbines were fitted, driving two propeller shafts. The forward end of each turbine casing contained the ahead stages, and the after end the astern stages. For larger ships, where higher powers were required with a lower speed of revolution of the propeller shafts, the high-pressure stages were fitted in an H.P. casing, the intermediate stages in an M.P. casing, and the remainder in an L.P. casing. Separate stages for going astern were provided in the M.P. and L.P. casings.

In a modern set of Brown Curtis turbines, driving the propeller

shaft through gearing, there are two turbines in each set. The H.P. turbine contains half the ahead stages, while the L.P. turbine contains the remainder of the ahead stages and the astern stages.

133. Parson's Turbine.—All the Parson's turbines fitted in the early turbine vessels, and also many of the Parson's turbines fitted in modern ships, are entirely of the reaction type. In expanding from the initial pressure to the condenser pressure, the steam passes through a large number of rows of blades, which are mounted alternately on a rotor, free to revolve in bearings, and in a casing surrounding the rotor. There is a small drop in pressure in each row of blades, and a consequent increase in the velocity of the steam relative to the blades. It is on account of the increase in velocity of the steam, that takes place in the rotor blades, that this turbine is called a reaction turbine. It must be clearly understood that there is only an increase in the velocity of the steam in the rotor blades if we consider the velocity relative to the moving blades. If the velocity of the steam in its passage through the turbine is considered relative to the casing blades, there is a decrease in velocity in the rotor blades, and an increase in the casing blades.

If a man walking down the corridor of a train away from the engine, starts to run, the velocity of the man relative to the train increases, but his velocity relative to the ground decreases. The man in the train cannot increase his velocity relative to the train, without producing a reaction on the train. The effect of this reaction, on the speed of the train, will not be noticeable, as the man is very light compared with the train, and the change in the velocity of the man is small. In a Parson's turbine, the force exerted on each blade is small, but there are many thousands of blades on the rotor.

In a Parson's turbine there is a lower pressure on the exit side of each row of blades than on the inlet side, and some steam will flow across the tips of the blades, instead of through the blade passages. This leakage is kept as low as possible, by arranging that the tips of the blades on the rotor almost touch the inside of the casing, and the tips of the casing blades almost touch the rotor.

In the Parson's turbine, used to drive the electric generators of ships, the expansion of the steam, from the initial pressure to the condenser pressure is carried out in one casing. In the larger turbines used for the propulsion of ships, the steam is partly expanded in an H.P. turbine, and then exhausted through an eduction pipe to an L.P. turbine, where the expansion is complete. The modern L.P. turbines are what is known as double flow. The steam is admitted to a steam belt in the casing, situated at about the middle of the rotor, and flows along the rotor in both directions, to an exhaust passage at each end.

Fig. 27 shows a Parson's H.P. turbine as fitted for driving a

propeller shaft through gearing. As the steam flows through the turbine the pressure drops, and the volume increases. To provide for the increase in volume of the steam, the internal diameter of the casing is increased in steps, and longer blades fitted. Each portion of the turbine, in which the blades are of the same height, is known as an expansion or stage. The H.P. turbine shown has six expansions. In addition to the main steam inlet to the first expansion, live steam can be admitted to the second expansion through a by-pass valve. The length of the blades in the second expansion being greater than in the first, opening the by-pass valve will increase the flow of steam and hence the power developed in the H.P. and L.P. turbines.

It is a common practice, in modern Parson's marine turbines, to fit an impulse wheel as the first stage in the H.P. and astern turbines. This impulse stage takes the place of a number of reaction stages, and so results in a shortening of the turbine ; also, at reduced powers, some of the nozzles can be shut off, and a high receiver pressure maintained. The higher the pressure from which the steam is expanded in the turbine, the greater will be the efficiency.

The construction of the rotor depends on the diameter, and on the maximum speed at which it is to revolve. For the large and relatively slow running direct drive turbines, the rotor consists of a thin steel drum shrunk and secured on to a wheel at each end. Small high-speed rotors are solid steel forgings, while the larger rotors of geared ships are made in two parts, as shown, or may be formed of a number of wheels shrunk and secured on to a spindle. The casing is in two halves, bolted together. It is made of cast steel for H.P. turbines and cast iron for L.P. There are four feet cast on the lower half of the casing ; these feet rest on the engine seating built up from the ship's hull. The two feet at the after end are bolted rigidly to the seating, while the two at the forward end are allowed to slide, to allow for expansion. The fore and aft expansion of the casing can be read off from an indicator on one of the *sliding feet.* In addition to the main bearings, which support the rotor, a thrust bearing, or *adjusting block*, is provided, to maintain the rotor in the correct axial position in the casing.

134. Dummy Piston.—The difference in pressure, on each side of each row of rotor blades in a Parson's turbine, produces, in single flow turbines, an axial thrust on the rotor. If one end of the rotor was exposed to the inlet pressure, and the other end to exhaust pressure, there would be an additional axial thrust in the same direction as the axial thrust on the blades. In practice the dummy piston prevents the inlet steam pressure acting on the end of the rotor, and both ends of the rotor are exposed to exhaust pressure. An extension of the rotor at the inlet end, known as the dummy

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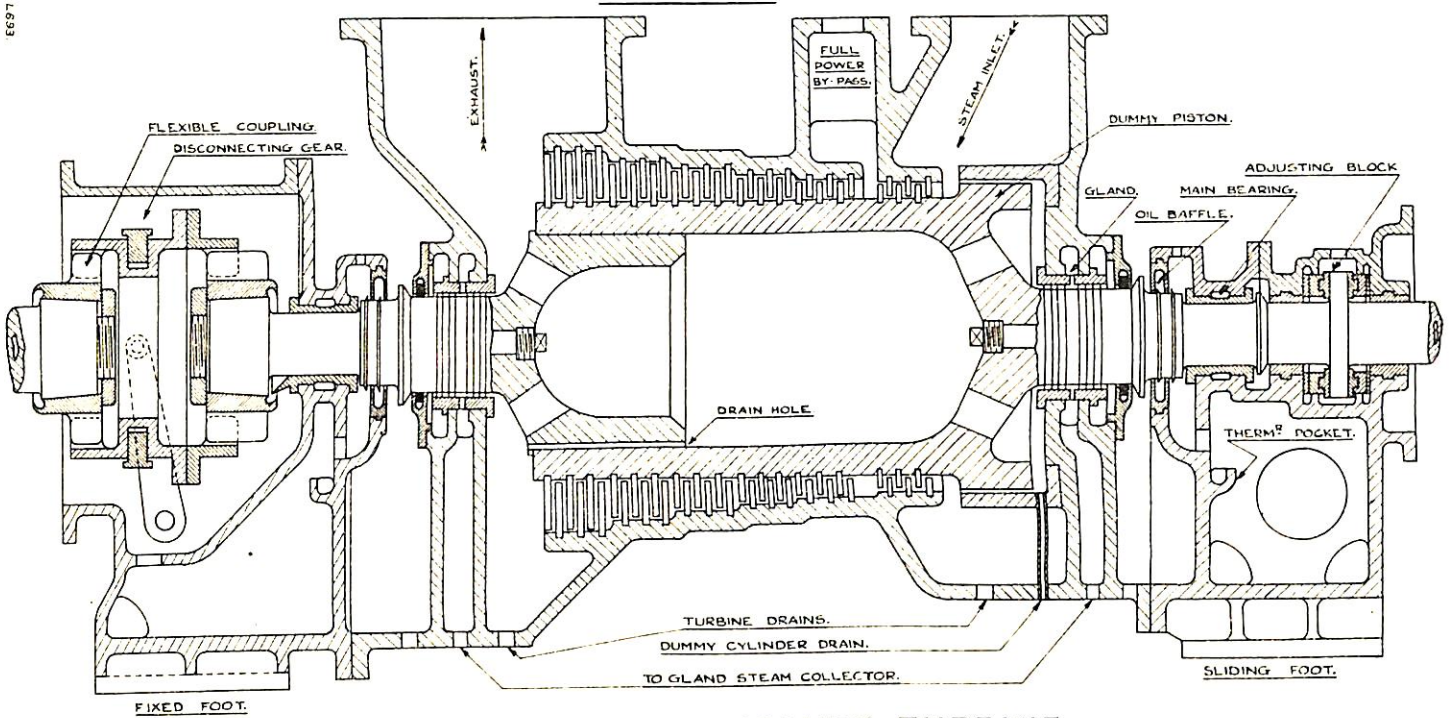
FIGURE 27.



PARSONS HIGH PRESSURE TURBINE.

piston, is surrounded by a steel cylinder. A number of fins, fitted in the dummy cylinder, almost touch the dummy piston. The small quantity of steam, which leaks past these fins, passes away to the exhaust end of the turbine, either through the rotor in the case of hollow rotors, or through external pipes, known as equalising pipes, in the case of solid rotors. It will be noticed in Fig. 27, that the diameter of the dummy piston is greater than the diameter of the rotor. The axial thrust on this annular area balances the axial thrust on the blades. In direct drive turbines the dummy piston may be smaller than the rotor, so that the thrust on the dummy piston, plus the thrust on the blades, balances the propeller thrust.

135. Turbine Glands.—A gland is fitted at each end of the turbine, where the spindle passes through the casing. These glands must prevent leakage of steam to the atmosphere when there is a pressure in the casing, or the leakage of air into the turbine when there is a vacuum in the casing. Any air leaking into the turbine will pass to the condenser, and cause a reduction in the vacuum.

In Brown Curtis turbines, the gland packing consists of carbon rings, as in the turbine described in Article 130.

In the Parson's turbines, what is known as fin packing, is fitted, This consists of a number of fins on the spindle, which almost touch a sleeve surrounding the spindle. There are also fins in the sleeve, which almost touch the spindle. In modern Parson's turbines, one ring of carbon packing is fitted in addition to the fin packing, as shown in Fig. 27.

When there is a pressure in the casing of a Parson's H.P. turbine some steam will leak past the fin packing. To prevent an excessive leakage of steam to the atmosphere, some of the steam leaking past the first few rows of fin packing can be lead away to the condenser. This leak-off steam is taken from a pocket about halfway along the gland. When there is a vacuum in the casing, steam can be admitted to this gland pocket. If a steam pressure of one or two pounds per square inch is maintained in the middle of the gland, leakage of air into the casing will be prevented. In the older ships, a separate valve is fitted to control the steam supply to each gland, and on the glands of H.P. turbines there is also a leak-off valve.

In a Parson's turbine, the pressure inside the casing in the vicinity of the gland is the same at both ends of the turbine (*see* Article 134). The glands of the L.P. turbines will have to be steam, packed at all powers. Steam must be admitted to the H.P. glands when the pressure in the H.P. exhaust, *i.e.*, the L.P. receiver pressure, is below atmospheric pressure. When the L.P. receiver pressure is above atmospheric pressure, the leak-off valves on the H.P. glands must be opened as necessary to prevent an excessive blow of steam from these glands. A slight leakage of steam for the gland will indicate that no air is leaking in through the gland.

In modern ships, steam supply and leak-off valves are not fitted to the turbine glands. The pockets of the glands of each set of main engines are connected to a vessel, known as a collector, in which a pressure of about 2 lb. per square inch is maintained by admitting steam or leaking off to the condenser as requisite.

136. Turbine Drains.—Drains are fitted at various points on the turbine casings to prevent water accumulating in the turbines, particularly when warming through. These drains are lead to the condenser. Valves are fitted on the drains from the ahead turbines, and these valves can be worked from the starting platform. In modern ships there are no valves on the drains from astern turbines, as the loss of steam during the short periods of astern running is unimportant. All turbine drains should be open when the turbines are stopped. *The drains on the ahead turbines should be shut when running ahead and open when running astern.* The blades in the ahead turbines will become overheated if the drains on these turbines are not opened when going astern.

137. Advantages and Methods of Speed Reducation.—Turbines designed to run at high speed are lighter, smaller, and more efficient, than slow-running turbines of the same power. In the early turbine vessels, the turbines were coupled direct to the propeller shaft and therefore revolved at the same speed as the propeller. It is not possible to produce a propeller which will run efficiently at very high speeds, and it was therefore necessary in direct-drive ships to employ slow-running turbines.

Two methods are now used, to allow of the turbines being run at high speed, and the propeller at a low speed. In what is known as electrical transmission, high-speed turbines drive dynamos, which supply current to slow-running motors coupled to the propeller shafts. On account of the weight of the dynamos and motors, and the complications involved, electrical transmission has not been used in any of H.M. ships. In all modern turbine-driven warships, the propeller shafts are driven through single-reduction gearing. Reduction gearing is also fitted in some turbine-driven auxiliaries, such as forced-draught fans and electric generators.

138. Main Reduction Gearing.—Each set of main engines of a modern turbine-driven vessel consists of a H.P. ahead turbine and a combined L.P. ahead and astern turbine, driving a propeller shaft through reduction gearing.

Each turbine drives a pinion, in which are cut helical teeth. The teeth on one half the driving length of the pinion are cut to form a right-handed helix, and on the other half a left-handed helix, in order that the axial thrust on one-half of the teeth shall balance the axial thrust on the other half. The pinion teeth mesh

with corresponding teeth on a large gear wheel, coupled to the propeller shaft. The number of teeth round the circumference of the gear wheel being about ten times as great as the number of teeth round the circumference of the pinion, the turbine revolves about ten times as fast as the propeller. The H.P. turbine and the L.P. turbine drive the same gear wheel. The H.P. pinion having a smaller number of teeth than the L.P. pinion, the H.P. turbine revolves at a higher speed than the L.P. The gear wheel and the two pinions are enclosed in a gear case, in which are provided bearings for the journals of the wheel and the two pinions. Oil is sprayed along the line of contact of each pinion and the gear wheel, to lubricate the working surface and prevent overheating.

139. Flexible Couplings.—The gear wheel is kept in the correct fore and aft position by the thrust block, which is fitted just abaft the gearing, and takes the thrust of the propeller. The pinions must be free to align themselves with the gear wheel, and their axial position must not be affected by the expansion of the turbine rotor. A sliding or flexible coupling is therefore fitted between the rotor and the pinion. Teeth cut inside a sleeve engage in slots, cut in collars secured to the pinion and turbine spindles. Rotation of the turbine is transmitted to the pinion through this sleeve. On account of the shape of the slotted collars, the coupling is often referred to as a star coupling.

140. Turbine Disconnecting Gear.—Provision is made so that, should the turbines of one set of machinery be damaged, the vessel may be driven with the other sets, without the damaged turbines revolving. In the latest ships the sleeves of the flexible couplings can be moved axially, so that the internal teeth no longer engage with the slots in the collar attached to the pinion, *see* Fig. 27. The turbines of any set of engine can thus be disconnected, and the gearing and propeller shaft allowed to revolve idly. In older vessels the two pinions must be lifted out of their bearings, or the turbines and gearing disconnected by parting a coupling on the shaft between the gear wheel and the thrust block.

141. Brakes.—In cruisers and larger ships brakes are fitted, so that any propeller shaft can be prevented from revolving, while the ship is towed or steamed at slow speed with the other shafts. The turning gear, fitted to turn the main engines in harbour, is not strong enough to keep a shaft from revolving under these conditions.

142. Cruising Turbines.—To propel a vessel at half speed, only about one-twentieth of the power developed at full speed is required. For this reason, the majority of steaming done by warships in peace time, is done at low speeds. The fitting of an impulse wheel to a Parson's turbine, in order to improve the efficiency at low powers,

has been mentioned in article 133. Where the extra weight can be accepted, it is more economical to provide special cruising turbines. These cruising turbines are designed to pass the reduced quantity of steam required at cruising speeds. After partial expansion in the cruising turbines, the steam passes through the H.P. and L.P. ahead turbines, where the expansion is completed. When higher speeds than that obtainable with the cruising turbines in use are required, steam is shut off from the cruising turbines and admitted to the H.P. turbines. Cruising turbines may be coupled direct to the forward end of the H.P. turbines. More usually the cruising turbine drives the H.P. turbine through gearing, the cruising turbine running at about twice the speed of the H.P. turbine.

143. Cruising Turbine Clutches.—Clutches are usually fitted so that the cruising turbines can be disconnected when not required. Geared cruising turbines must always be disconnected when steaming at speeds above that for which these turbines are designed. In older ships a steam whistle blows if the speed of the cruising turbine rises above the designed revolutions. In modern ships an interlock is fitted, which prevents steam being opened to the H.P. turbine while the cruising turbine is connected.

In ships with direct-drive cruising turbines, and in the older ships with geared cruisers, an ordinary sliding clutch is fitted, and it is necessary to stop the engine to clutch in the cruising turbine.

Two types of clutch are now fitted which enable geared cruising turbines to be connected without stopping the engines. In smaller vessels a modified form of sliding clutch is fitted. To couple up without stopping, the cruising turbine is speeded up under steam, until the two halves of the clutch are running at approximately the same speed. To bring about a final adjustment of the speed, a friction clutch is engaged momentarily, before engaging the main clutch. In larger vessels with geared cruising turbines, a hydraulic coupling of the Vulcan type is fitted. There is no metallic contact between the two halves of this clutch. Motion is transmitted by oil, discharged from one half of the clutch, impinging on vanes in the other half. The clutch is connected and disconnected by filling and emptying the chamber between the two halves of the clutch.

144. Emergency Governors.—When a turbine is revolving stresses are set up in the rotating parts, due to centrifugal forces. The higher the speed of rotation, the greater will be these stresses. If the speed of rotation is allowed to exceed the maximum for which the turbine is designed, the rotor may break and cause a considerable amount of damage. To prevent this happening, all geared cruising turbines and turbines of auxiliary machinery are fitted with overspeed governors. If the designed maximum speed is exceeded this

governor trips, and the steam valve of the turbine is shut by a spring. The overspeed governor can be tripped by pressing a button, or by moving a short lever. To reset the governor after tripping, the steam valve must first be closed by hand. On starting a turbine-driven auxiliary, if time permits, the governor should be tripped and re-set, to ensure that the mechanism is free.

Such machinery should always be stopped by first tripping the governors and then closing the steam and exhaust and other valves. The governor should then be re-set.

145. Arrangement of Main Turbines.—The only ships remaining in service in the British Navy which are fitted with direct-drive turbines are some of the older capital ships and aircraft carriers. Most of these ships have two sets of Parson's turbines driving four shafts. On the outer or wing shafts are the H.P. ahead and the H.P. astern turbines, and on the inner or centre shafts the L.P. ahead and L.P. astern turbines incorporated in the same casing. Both L.P. turbines are in a centre engine room, with a wing engine room containing the H.P. turbines on each side. In H.M.S. Repulse, which has Brown Curtis turbines, there are three ahead turbines in each set, the M.P. ahead turbines and the H.P. astern being on the wing shafts, and the H.P. ahead on the centre shafts, forward of the L.P. turbines.

The arrangements of geared turbine propelling machinery vary in different classes of ship. Destroyers have two shafts, and two sets of turbines in a common engine room. The gearing may be in the engine room or in a compartment abaft the engine room. Cruisers generally have four shafts, the two sets of turbines for two wing shafts being in one engine room, and the two sets for the centre shafts in another, situated further aft. Some battleships have two shafts and some four, each set of machinery being in a separate engine room. A few aircraft carriers have three shafts and three sets of geared turbines.

In ships with two or three shaft arrangements the boiler rooms are situated forward of engine rooms. In some ships with four shafts, half the boilers are placed forward of the forward engine room and the others between the forward and the after engine rooms.

146. Measurement of Horse-Power of Main Engines.—Larger vessels are provided with instruments for measuring the power developed by the main engines. Instruments, called indicators, are used on reciprocating steam engines and on internal combustion engines, and by their means *indicator diagrams* may be obtained from any cylinder. An indicator diagram shows the pressure in a cylinder at any part of the stroke, and from this information the

mean effective pressure and the *indicated horse-power* may be calculated.

For turbines the term indicated horse-power is not used, because it is not convenient to measure the actual work done by the steam in a turbine. The power transmitted to a propeller shaft may however be measured, because the transmission causes a slight twist in the shaft and the greater the power transmitted the larger the twist. By means of an instrument called a *torsionmeter* it is possible to measure the amount of twist in a revolving shaft, and so obtain the twisting moment or torque in the shaft. Knowing the torque in the shaft, and the speed at which it is revolving, the power transmitted may be calculated, and is known as the *shaft horse-power*. A torsionmeter is fitted on each propeller shaft in cruisers and larger vessels.

147. Warming Through Turbines.—When a turbine is warmed through preparatory to use, the increase in temperature causes expansion of all the metal parts. If care is not taken, this expansion may cause such distortion that contact will take place between the rotor and the casing, and damage to the blades may result if the rotor is revolved while this condition exists. Serious distortion is more likely to occur in a large turbine, and particular care is necessary with Parson's turbines on account of the small blade clearances. (*See* Article 133.) *It is of the utmost importance that high temperature steam shall not be allowed to pass through a turbine while the rotor remains at rest, as this may cause serious distortion.*

The large main turbines of direct drive ships are fitted with connections for warming through with low pressure steam from the gland steam system. By admitting steam through these connections over a period of some hours, slow and fairly uniform heating of the turbines can be achieved. The expansion of the turbine casing, as shown by the movement of the sliding feet, indicates when a turbine has been warmed sufficiently. When additional boilers are being lit up, these are opened out on to the main steam range, and the hot air and low-pressure steam from these boilers allowed to pass through the ahead manoeuvring valves to the main turbines, thus gradually warming the main steam pipes and assisting in warming the turbines.

The smaller main turbines of geared ships are warmed by admitting steam only through the manoeuvring valves. Heating steam connections are not fitted to the main turbines of modern ships. Uniform heating is best achieved by revolving the rotor slowly by steam during the warming up process, and nozzle control valves, where fitted, should all be open in order to give as even a distributing steam as possible.

In the case of main turbines, when possible, hot air and low-

pressure steam from boilers being lit up is used to give a slight preliminary heating with the turbine rotors at rest. The manoeuvring valves must be gradually closed when a steam pressure starts to show in the boilers, to prevent local overheating, and care must be taken that L.P. turbines are not heated to above their running temperature. The final heating is carried out with the rotors revolving, after working up a vacuum of about 20 inches in the condenser. To prevent bringing an undue strain on the ship's cable or mooring wires, main turbines are moved slowly for a few revolutions, both ahead and astern, every two or three minutes during the final warming up. *Permission must be obtained from the officer of the watch on deck before moving the main engines, to ensure that wires are not allowed to get foul of the propellers and that boats are not damaged.*

Before admitting steam to the main turbines, either through the manoeuvring valves, or through heating steam connections, the main circulating pumps must be started, and while warming through the condensers must be kept pumped out by running the air or extraction pumps as necessary. While warming through and starting a turbine a considerable amount of water will be formed by the condensation of steam ; all drains in the turbines must be kept open until all the metal on the turbine has been raised to the running temperature. Water in a turbine will prevent uniform heating and may cause damage to the blades when the turbine is moved. *Before attempting to move a turbine under steam, care must be taken that the turning gear is disconnected and that oil is circulating through the bearings.*

Instructions for warming through and starting a turbo-generator will be found in Article 203. All other auxiliary turbines are of the single-wheel impulse type, and on account of their small size and relatively large blade clearances, damage due to distortion is unlikely to occur. Before starting an auxiliary turbine, attention should be paid to the lubrication arrangements, *see* Article 155, and the steam and exhaust pipes should be drained, *see* Article 175. The turbine may be run slowly up to its running speed and the emergency governor tried, *see* Article 144. Turbine driven rotary pumps should be started with the suction valve open and the discharge valve shut.

CHAPTER X.

BEARINGS AND THEIR LUBRICATION.

148. Friction in Bearings.—Friction tends to oppose the sliding of one surface over another in a bearing, and a certain amount of power has to be expended to overcome this friction. The power lost due to friction is converted into heat, which raises the temperature of the bearing. If the friction is excessive, the rise in temperature may be sufficient to cause damage to the bearing surface. The application of oil or grease to the bearing surface reduces the friction considerably.

The amount of friction in a lubricated bearing depends on the type of bearing, on the condition of the surfaces and of what material these are made, and on what lubricant is used. The quantity of lubricant supplied may also affect the friction in a bearing. A certain amount of clearance must be allowed in a bearing, to ensure that the lubricant can flow over the whole of the surface. Grooves, known as *oilways*, are sometimes cut in a bearing to facilitate the flow of the oil.

If proper attention is not paid to the lubrication of bearings, serious damage may result, and the amount of work necessary to maintain the machinery in good condition will be materially increased.

If a bearing becomes hot, additional lubricant must be supplied, and the condition reported to the Engineer Officer of the watch or day. Water is not to be used for cooling a bearing without orders.

149. Shaft Bearings.—The normal type of bearing fitted in marine engines consists of a gunmetal bush in halves, with a collar at each end to prevent axial movement of the bush. Each half of the bush is known as a brass, the two halves together forming a pair of brasses. Brasses are usually lined with one or another of a group of alloys, known as *white metals*. These are alloys of tin with small quantities of other metals. They are relatively soft, and have a low melting point. The advantages of the white-metal lining are, that it reduces the friction in the bearing, and it can be renewed by melting out the old lining and running in new.

The lubrication of bearings which are under water is difficult. Such bearings are often lined with a hard wood called *lignum vitae*, or with *india rubber*. No oil or grease is used for lignum vitae or india rubber bearings.

Ball and roller bearings are used for light loads, when it is particularly desirable to reduce the friction, or easy starting is

essential. These bearings are less dependent on lubrication than plain bearings. For slow speeds it suffices to supply a little oil or grease periodically to prevent the bearings rusting, but for high speeds provision is made to keep the bearings full of oil. Grease-lubricated bearings must not be overcharged, as this would interfere with the free motion of the balls or rollers. A form of roller bearing with long thin rollers is known as a *needle bearing*.

150. Michell Thrust Bearings.—These bearings are fitted in all ships with geared turbines, to take the thrust of the propeller. Turbine thrust or adjusting blocks are now also of this type, where the unbalanced thrust of the steam on the rotor is appreciable. In ships with direct-drive turbines the thrust on the propeller is largely balanced by the steam thrust in the turbine, and any unbalanced thrust is taken by the turbine adjusting block. (*See* article 134.)

In the case of a thrust collar bearing on a fixed surface, it is not possible to ensure an adequate supply of lubricant to the bearing surfaces, if the load is heavy. Before the invention of the Michell thrust bearing, it was necessary to provide a large number of thrust collars to take the thrust of a propeller. Michell showed that only one collar was necessary, if the bearing surface was made up of a number of segments or pads, each supported in such a way that it could tilt. The collar, with pads on each side, is enclosed in a casing, which is kept full of oil. When the load comes on the pads on one side of the collar, each of these pads takes up a position, so that its leading edge is about a thousandth of an inch farther from the surface of the collar than the trailing edge. This inclination of the pads facilitates the maintenance of a film of oil between the pads and the collar.

151. Methods of Lubrication.—Some bearings, such as the Michell thrust bearing and ball and roller bearings on high-speed spindles, are run submerged in oil. For other bearings the lubricant must be supplied at a sufficient rate to ensure adequate lubrication of the bearing surfaces. When provision is not made to recover the oil, the rate of supply should not be greater than is necessary to keep the bearing surfaces oily and prevent overheating.

Small bearings of slow-running auxiliary engines, such as direct-acting pumps, are supplied at intervals with a small quantity of oil by means of an oil feeder. When it is important to ensure a more uniform supply of oil, and provision is not made to recover the oil used, what is known as *drip-lubrication* is fitted. This provides a small and more or less uniform supply of oil to the bearing.

For turbines and high-speed reciprocating engines, what is known as *forced lubrication* is used. Oil is supplied to the bearings at a much greater rate by means of a pump, and provision is made

to collect the oil leaving the bearings, so that it can be used over and over again.

For lightly loaded bearings, sufficient oil can be raised from a sump under the bearing, by what is known as *ring lubrication.* A somewhat similar method is used in self-lubricating plummer blocks.

For some bearings where it is difficult to provide oil lubrication, *grease lubrication* is fitted. The grease is forced into the bearing surfaces by means of a grease pump or Stauffer lubricator. Care must be taken that the grease used is one suitable for the particular bearing. Trouble may be experienced if the wrong grease is used, or if a different grease is added to the grease already there.

152. Drip Lubrication.—The method of lubrication generally used for steam reciprocating engines was to allow a small quantity of oil to drip into each bearing. This method is still used for the main engines of small vessels where steam reciprocating engines are fitted, and for some auxiliary engines. A number of oil boxes are fitted at convenient positions on the engine, and pipes are led from these boxes, either to the bearing itself or, when this is not possible, to a position from which the oil can drip into the bearing.

The rate of supply of oil is controlled, either by a cock on the pipe where it leaves the oil box, or more usually by arranging that the oil must siphon from the box into each tube through a worsted. The oil pipes are extended inside the box to above the oil level. One end of a piece of worsted is pushed down the pipe by means of a piece of wire to which it is attached, and the other end is weighted to keep it at the bottom of the box. The worsted should extend inside the pipe to the level of the bottom of the box.

As the oil supplied to the bearings is not recovered, the rate of supply should be just sufficient to keep each bearing adequately lubricated. The rate at which it is siphoned through a worsted depends on the depth of oil in the box. Filling the oil boxes to too high a level serves no useful purpose, and results in serious wastage of oil. The rate of supply can be increased by fitting more or larger worsteds. When an engine is not in use the worsted should be taken out of the pipes inside the oil box, and replaced when the engine is again required. The lids of oil boxes should be kept closed, to prevent water or dirt getting into the boxes. If water finds its way into a box, the oil will float on top of the water. Oil boxes should occasionally be emptied with a syringe, to ensure that there is no water present.

153. Advantages of Forced Lubrication.—By supplying oil under pressure to a shaft bearing two desirable results are achieved. Firstly, the clearance between the journal and the bearing being kept full of oil, when the shaft is revolving at above a certain minimum speed, a thicker film of oil is maintained between the

journal and the bottom brass than is the case with drip lubrication. Secondly, the large quantity of oil passing through the bearing keeps the journal and the brasses cool. The oil is generally passed through some form of cooler between the pump and the bearings. Forced lubrication, will, when conditions are favourable to the formation of this thicker film of oil, reduce the friction in the bearing and practically eliminate wear of the bearing surface.

154. Main Turbine Forced Lubrication.—For all bearings and gearing of each set of main turbines oil is drawn from an *oil-drain tank*, into which all bearing sumps and the gear-case drain, by a steam-driven forced-lubrication pump. Where two sets of main turbines are in the same engine room, *cross connections* are fitted on the discharge and on the suction side of the pumps. These cross connections are normally kept open. There is also a *levelling valve* between the two oil-drain tanks. In small ships this levelling valve is kept shut if the vessel has a list or is rolling heavily, to prevent all the oil running from one tank into the other. Under these conditions particular attention must be paid to the level of oil in the tanks.

In larger ships *stand-by pumps* are fitted, either one for each set of turbines or one for two sets when they are in the same engine room. In the latest ships the stand-by pumps are electrically driven, and start automatically if the steam pump stops.

In small ships stand-by pumps may not be provided. Should the forced-lubrication pump of one set of machinery stop, the other pump must be relied upon to supply both sets.

Each oil drain-tank is fitted with an *indicator* to show the amount of oil in the tank. Any change in the level in an oil drain-tank must be reported to the engineer officer of the watch immediately. Additional oil can be run down from the oil storage tanks when necessary.

To prevent any dirt which may be in the oil reaching the bearings, *strainers* are fitted on the discharge side of the pump. In the older ships, where muslin is used in the strainers, it is necessary to open them out for cleaning when choked. The strainers are therefore fitted in pairs. Only one of each pair should be in use at a time, and the other should be available to change over to when necessary. The strainers fitted in the latest ships can be cleaned while in use. Movement of a handle on the strainer either revolves the filtering cartridge across a scraper, or brings about a reversal of flow through a section of the strainer.

On the old type of *oil coolers* the oil passes through tubes around which sea water is circulated. In the modern type sea water is circulated through the tubes and the oil passes around the outside. A pipe from the main circulator discharge supplies cooling water

to each oil cooler. Arrangements are made so that, should a leak develop in an oil cooler, the oil can be by-passed, and the cooler shut off until the defect has been made good.

A supply of oil is led from the forced lubrication system to each bearing, and to the oil sprayers on the gear-case where gearing is fitted. On each bearing there is a *gauge* to indicate the pressure of the oil at the bearing, and a test cock. The *test cocks* are used to check that oil is reaching the bearing. The oil issuing from the test cock when it is opened is caught in a small cup, and runs down to the oil sump under the bearing. In modern ships *sight flow indicators* are fitted on the supply to each sprayer on the gear-case, and on the return from each turbine-adjusting block. It can be ascertained by looking at these indicators that oil is flowing through the pipe.

To prevent oil leaking out along the shafts and so being wasted, it is necessary either to fit glands with a turn of soft packing or *oil throwers*. An oil thrower consists of a small collar with a sharp edge turned on the shaft. When the shaft is revolving centrifugal force causes the oil to be thrown off from the edge of the collar, and baffles are so arranged that this oil is caught and drained to the sump.

Under each bearing is a *thermometer pocket*, over which the oil leaving the bearing flows. It is usual to put some oil in these pockets, to ensure that thermometers placed in them shall quickly register the temperature of the oil from the bearing. (Mercury is used in some thermometer pockets, such as on the oil-fuel system, where it is not necessary to remove the thermometer to read it). It is not possible to lay down the maximum safe temperature of the oil leaving a bearing. Consideration must be given to the temperature at which the bearing normally runs. Any rise of temperature above the normal should be reported immediately to the engineer officer of the watch.

The top of the oil-drain tanks, the gear-case and the bearing sumps being in communication with the moist air in the engine room, the oil in the forced lubrication system will slowly become contaminated with water. If this water is not removed the lubricating property of the oil will be impaired and the journals will rust. A *special mineral oil*, from which water will readily separate, is therefore used in forced-lubrication systems. When the oil is not being circulated most of the oil in the system will drain down to the oil-drain tanks, and any water present will collect in the bottom of the tank. A hand pump is provided to pump out any water which settles to the bottom of the oil-drain tanks when in harbour.

In modern ships *centrifugal separators* are fitted, to enable any water present to be separated from the oil, without having to wait

for it to settle out when in harbour. A small pump circulates oil from the oil-drain tank through the separator, in which the oil passes through a vessel which is revolving at high speed. Centrifugal force causes the water to be separated out faster and more thoroughly than can be achieved by gravity. The purified oil returns to the oil-drain tank, and the separated water drains to the bilge. Any dirt present in the oil collects in the separator, which must be opened out and cleaned periodically.

155. Forced Lubrication for Auxiliary Engines.—There are a few turbine-driven auxiliaries, such as turbo feed pumps, for which ring lubricators, described in the next article, will give adequate lubrication. All other turbine auxiliaries, all internal combustion engines, and high-speed steam reciprocating auxiliaries, are provided with their own forced-lubrication system.

The bed of the engine or the bottom of the crank chamber is formed into an oil well, into which the oil from all the bearings drains. A dip stick is fitted to allow of the depth of the oil in the well being checked from time to time. A drain cock at the bottom of the well allows of water being drained off periodically, or of the well being emptied when necessary to change the oil. In the case of internal-combustion engines, the lubricating oil becomes contaminated with fuel oil and carbon, and must be changed more frequently than is necessary with steam engines. (*See* article 220.)

A small pump, driven by the engine, takes its suction from the oil well and delivers oil under pressure to the bearings. In reciprocating engines the oil for the crank pin bearing is led through a hole in the crank shaft from an adjacent main bearing. Lubrication for the crosshead or gudgeon pin bearing may be supplied from the crank-pin bearing through a hole in the connecting rod, but in small engines sufficient lubricant for this bearing is supplied by oil splashed up from the crank case. In the case of geared turbine-driven auxiliaries, the pump also provides the oil sprays for the gearing. A gauge is fitted to show the pressure on the discharge side of the pump. To allow of the pressure being regulated, it was the practice to provide a hand-controlled valve through which some of the oil from the discharge side of the pump could be by-passed back to the sump. With this arrangement the oil pressure must be adjusted when the engine is started, and re-adjusted from time to time as the oil becomes warmer and more fluid. In all modern engines a spring-loaded valve is fitted instead of a hand-controlled valve. *An engine should not be run if the oil pump fails to maintain a reasonable pressure. An engine must be stopped immediately if there is a sudden drop in the oil pressure or serious damage may be done.*

In addition to the oil pump driven by the engine, a hand pump

often fitted, so that oil can be pumped round the system while starting the engine.

The oil is filtered either by fitting a gauze filter over the pump suction in the oil well, or providing an Auto-Klean filter on the discharge side of the pump. Gauze filters can be removed for cleaning when the engine is not running. Auto-Klean filters can be cleaned when in use by turning a handle, which revolves the filtering cartridge against a number of scrapers.

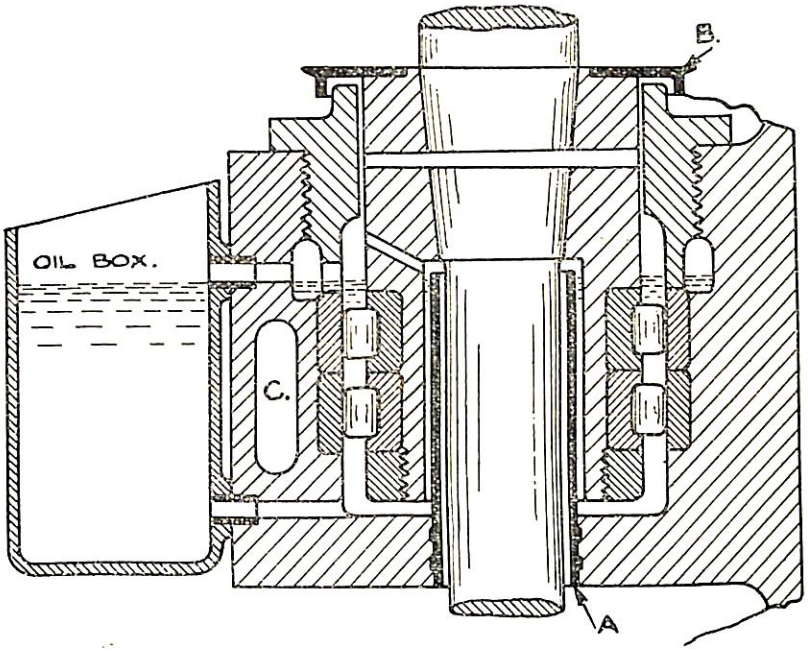
It is generally necessary to arrange for cooling the oil. An external oil cooler may be fitted or cooling tubes or coils may be fitted in the oil well. Where no other water service is available a small circulating water pump driven by the engine is fitted. In modern forced-draught fans a coil, through which the oil passes, is cooled by the air discharged from the fan.

A watch should be kept on the temperature of the oil in the oil well, and any undue rise of temperature is to be reported to the Engineer Officer of the watch or day. *Should a sudden rise of temperature of the oil in the well, or the smell of hot oil, indicate that a bearing is seriously overheated the engine should be eased up at once, and if there are any naked lights near the engine, these should be extinguished or removed to a safe distance.* (*See* articles 95 and 99.)

156. Ring Lubrication.—The bearings of turbo feed pumps and ventilation fans are fitted with ring lubricators. A part of the top cap of the bearing is cut away to expose the journal, and an oil sump is provided under the bearing. A ring is fitted over the bearing, so that it rests on the exposed part of the journal, and the bottom of the ring dips in the sump. When the journal revolves the ring is carried round, picking up oil as it passes through the sump and depositing it on the top of the journal.

157. Oil Bath for Ball and Roller Bearings.—Small auxiliary turbines with vertical spindles are commonly fitted with ball or roller bearings. When a forced-lubrication system is not fitted to the engine, it is arranged that these bearings run in an oil bath. An oil box is fitted to each bearing, and is connected to the bearing at the top and at the bottom, as shown in Fig. 28. A short length of tube A, expanded into the bearing housing at the bottom, prevents the oil running out of the bearing. If the oil box is filled to above the lower edge of the top connection to the bearing, oil will run over the top of tube A and down the spindle. The thrower B prevents water passing down the spindle into the bearing. Sea water is circulated through the space C in the housing to keep the bearing cool. A drain cock is fitted to the oil box, to enable the oil to be drawn off occasionally and replaced by fresh oil.

FIG: 28.



OIL BATH FOR ROLLER BEARING

158. Self-Lubricating Plummer Blocks.—The bearings fitted to support the propeller shaft, between the after bearing of the main engines or gearing, and the stern tube where the shaft passes through the hull of the ship, are known as plummer blocks. In the older turbine-driven ships these bearings are supplied with oil from the main engine forced-lubrication system. The modern practice is to fit self-lubricating plummer block bearings. Under each bearing is an oil sump or well, in which enough oil is kept to cover the bottom of one or two collars fitted on the shaft. When the shaft is revolving, oil picked up by the collars is scraped off by a wiper, which rests on the top of the collar. This oil runs from the wiper through the bearing, and back to the sump. A gland is fitted at each end of the bearing to prevent loss of oil. A dip stick, marked to show the correct level of oil in the well, is fitted. In some ships the oil in the well can be cooled, if necessary, by circulating water around the outside.

159. Stern Tube and "A" Bracket Bearings.—The tube around the propeller shaft, where it passes through the hull of the ship, has a bush fitted at each end to support the shaft, and a gland

at the inboard end to prevent the ingress of water. It is generally necessary to provide a further bearing for the shaft close to the propeller. This bearing consists of a bush fitted in a bracket secured to the hull of the ship, and is known as "A" bracket bearing.

Large propeller shafts are fitted with gunmetal sleeves or liners in way of the stern tube and "A" bracket bearings, and the bushes are lined with strips of lignum vitae. Neither oil nor grease are used in these bearings. The sea water keeps the bearing surfaces cool, and to a certain extent acts as a lubricant. If required a flow of water through the stern tube bushes can be obtained, either by opening a cock on the inboard side of the tube, or by discharging water from the firemain out through the tube.

The propeller shafts of destroyers and other small vessels are not generally fitted with gunmetal liners. White metalled bushes are used for shafts which are not fitted with liners, and provision is made to supply grease to the bearing surfaces from a grease press fitted in the ship. The use of grease has the disadvantage of restricting the flow of cooling water through the bearing. In a few small ships the stern tube and "A" bracket bearings are fitted with sealing rings at each end, and the bearings are kept charged with oil by means of a hand pump.

The "A" bracket bushes of some destroyers are lined with strips of india-rubber, the shafts in this case being fitted with gunmetal liners.

160. Lubricants.—Practically all the lubricating oils now used are derived from petroleum. These oils are known as mineral oils to distinguish them from oils derived from vegetable and animal sources. While vegetable oils are in general superior to mineral oils in lubricating properties, they are very much more expensive. Also they are unsuitable for forced lubrication, as they do not separate readily from water, and tend to thicken if used continuously. Compound oils, which are made by the addition of some vegetable oil to a mineral oil, are used for certain purposes. Lubricating greases are mixtures of a mineral oil and a soap. Different greases are supplied for different purposes and care must be taken that the correct grease is used.

The lubricating oils and greases in general use in H.M. ships are :—

Special mineral oil.—For turbine forced-lubrication systems, and all auxiliary engines except those for which a special oil is supplied. Water will separate readily from this oil.

Admiralty compound oil.—For external lubrication of reciprocating engines not fitted for forced lubrication, and for internal lubrication of the air cylinders of air compressors other than those of E.A. plants.

High flash-point mineral oil.—For the primary compressors of E.A. plants. (Water only must be used in the secondary compressors.)

Internal combustion engine lubricating oil.—For I.C.E. generators, except those of the sleeve-valve type, and motor boats, except motor torpedo boats and boats attached to aircraft carriers. (For the motor boats of aircraft carriers and for motor torpedo boats a special oil supplied for aircraft engines is used.)

Mineral non-freezing oil.—For sealing the compressor glands of the main refrigerating machinery, and for the lubrication of the working parts where the lubricant comes in contact with the refrigerant. (For automatic domestic refrigerators the special oil recommended by the makers should be used.)

Heavy filtered mineral oil.—For the internal lubrication of steam cylinders and slide chests.

Light torpoyl.—For turbo-meters and other delicate mechanism which require a thin lubricating oil.

Stern tube grease.—For white metalled stern tubes and "A" brackets.

Gremontine and Cooper's No. 4 lubricants.—For grease caps and guns in pressure grease lubrication.

Belmoline R.B.—For grease lubrication of ball or roller bearings.

V.B.B. (Drysdale Petroleum Jelly).—For the lubrication of the under-water bearings of pumps.

Reid's lubricating compound.—For pneumatic transmission gear.

Anti-friction or Bellville grease.—For greasing the asbestos packing used in piston rod, slide rod and other glands.

For the preservation of machinery and spare gear *mineral grease* is used, and for leather hoses a mixture of equal parts of *neats-foot and cod oils.*

CHAPTER XI.

MAIN AND AUXILIARY STEAM SYSTEMS, FEED HEATING, AND CLOSED EXHAUST.

161. Main Steam Range.—The arrangement of the main steam pipes, through which the steam passes from the boilers to the main engines, differ in different classes of ships. In the older ships there are two large main steam pipes in the boiler rooms, the steam from the forward boilers passing to the engine room down one side of the ship, and the steam for the after boilers passing down the other side. In ships with a large number of boilers there are, in addition to the stop valve on each boiler, *sectional valves* where the steam from each group of boilers joins the main steam pipe. When the arrangement is such that only the after length of a main steam pipe may be in use, it is possible to shut off the forward length by closing a valve on the main steam pipe, known as an *isolating valve.*

Modern ships have a smaller number of boilers of larger output. There are generally two main stop valves per boiler, one on each superheater, and no sectional valves are fitted. A separate main steam pipe is fitted for each group of boilers in larger ships, while in the latest destroyers there are two main steam pipes for each boiler.

On each main steam pipe, when it enters the engine room, an *emergency bulkhead valve* is fitted. These valves serve the double purpose of isolating valves and emergency valves. In addition to hand operating gear for opening and closing the valve, they are fitted with a cylinder into which steam can be admitted to close the valve quickly, in the event of damage to the main engines or main steam pipes in the engine room. The steam-control valve of each emergency valve can be operated either from the engine room or from a convenient position on the deck above the engine room. From the emergency bulkhead valves the steam passes to the regulating or *manoeuvring valves,* through which steam is admitted either to the ahead or astern turbines. *Strainers* are fitted where the steam enters the turbines, to intercept any foreign matter which may have been accidentally left in the steam pipes. Cross connection pipes are fitted connecting the various main steam pipes on the engine side of the emergency bulkhead valves, and a *cross connection valve* is fitted on each of these pipes. The cross connection valves must be open when it is desired to supply steam to all the main engines from one group of boilers.

Metals expand when they are heated, and therefore steam pipes are longer when steam is in than when they are empty and cold. To avoid displacement of machinery, bulkheads, etc., allowance must be made for the expansion of all steam pipes. The simplest method is to provide suitable bends in the pipe, so that the pipe can flex as necessary. To increase the flexibility of large steel steam pipes, they are corrugated before being bent; such corrugated lengths of pipe are called *Aiton bends.*

An alternative method, that has been commonly used for large pipes, is to fit some form of expansion joint. One portion of a straight pipe may be allowed to expand into the other portion, or through a box containing a right-angle branch. Flexibility may be provided, where a branch joins a pipe, by introducing a shorter length of pipe with a ball and socket joint at each end. These expansion joints must be fitted with glands to prevent the leakage of steam, and they are therefore called *expansion glands.* With saturated steam these expansion joints are satisfactory, if the packing in the glands is renewed occasionally. They are not suitable for superheated steam, and in all modern ships the necessary flexibility is provided by fitting bent pipes.

162. Steam for Auxiliary Engines, etc.—A separate range or ranges of pipes are provided to supply steam to the auxiliary machinery. While it is desirable where possible to supply superheated steam for turbine-driven auxiliaries, saturated steam is more satisfactory for reciprocating engines. Saturated steam is also used for evaporators, turbine glands, and for oil fuel and mess deck heaters. In all ships with superheaters two separate auxiliary steam ranges are provided, one for superheated steam and the other for saturated steam.

163. Auxiliary Boiler.—In some ships a small auxiliary boiler is fitted, which will supply sufficient steam for the essential auxiliaries when in harbour. Some auxiliary boilers are fitted with superheaters and can supply steam to both the saturated and the superheated auxiliary steam ranges. When electric current for lights, etc., can be provided by diesel generators, the auxiliary boiler supplies saturated steam only.

When the auxiliary boiler is not fitted with superheaters, it is designed to generate steam at a lower pressure than the main boilers, and in these ships the auxiliary saturated steam range is also designed for this lower pressure. At sea, a supply of saturated steam is taken for the main boilers through a reducing valve. Safety valves are fitted on the saturated steam range, to ensure that the pressure shall not under these conditions exceed the pressure for which the range is designed. An electrically driven fan supplies air through a trunk to the auxiliary boiler. There is a supply to one

turbo-driven fan in each boiler room from auxiliary saturated range, so that this fan may be run with saturated steam from the auxiliary boiler, when lighting up main boilers.

In the latest destroyers and gunboats, a small automatically-controlled oil-fired boiler is fitted, to supply steam for ship's heating only.

164. Auxiliary Saturated Steam Range.—On the steam drum of each boiler is fitted a small stop valve, through which steam can be admitted to the saturated steam range. This range extends through the machinery spaces, with a branch to each reciprocating auxiliary, evaporator, etc. Steam for ship's heaters, oil fuel tank heaters, and other purposes for which low-pressure saturated steam is required, is taken for this range through a *reducing valve*. This valve automatically opens and closes, as necessary to maintain the required pressure in the heating system. Steam may be required in the ship heating system during dockyard refit, when the ship's boilers are not available. A connection is provided on the auxiliary saturated range to which a portable boiler, placed alongside the ship, can be connected.

In ships which keep steam in harbour, an alternative lead is provided between the forward boiler room and the after engine room, and the necessary cross connection and isolating valves fitted, in order that lengths of the auxiliary steam range may be shut off when necessary to remake joints or refit valves. A valve, known as a *master valve*, is fitted at the junction of each branch with the auxiliary steam range. Except when steam is required in a branch the master valve is kept shut, to avoid the accumulation of water in the branch pipe. With the master valve shut, the steam valve on the engine can be refitted. In small vessels which do not keep steam in harbour, there is generally only one valve between the auxiliary steam range and each auxiliary engine.

Whenever isolating or master valves are shut to allow of some repair being made, the handwheels should be lashed to prevent their being opened accidentally. *A lashed valve should never be opened, until it has been ascertained that the reason for which it was lashed no longer holds.*

165. Auxiliary Superheated Steam System.—In cruisers and larger ships a common auxiliary superheated range is fitted throughout all boiler rooms and engine rooms, with an isolating valve at each bulkhead. An auxiliary superheated stop valve is fitted on the outlet side of the superheaters in each boiler room, with a connection to this range. With the isolating valves open, any boiler can supply superheated steam to all turbine-driven auxiliaries. There is also in each engine room a cross connection between the main and auxiliary superheated ranges, in order that in action the isolating

valves may be shut. The auxiliaries in each boiler room are then supplied only from their own boilers, and the auxiliaries in each engine room from the main steam system. As in the case of the saturated auxiliary range, master valves are fitted only in ships which keep steam in harbour.

In small vessels which do not normally keep steam in harbour, the auxiliary superheated steam system in one machinery space is not connected to the similar systems in other machinery spaces; turbine-driven auxiliaries in the engine room, and in boiler rooms in which a boiler is not alight, can only be supplied with superheated steam when the main steam range is flooded. In destroyers, to allow of a turbo auxiliary in the engine room being run with saturated steam, when the main steam range is not flooded, a cross connection is provided between the auxiliary superheated steam system and the auxiliary saturated steam range in the engine room. This cross connection is fitted for use in emergency, and is either made portable or fitted with a locked valve.

166. The Closed Exhaust System.—The efficiency of a steam plant can be increased by using steam, which has been partially expanded in the main and auxiliary engines, to raise the temperature of the boiler feed water. Also distilled water which is required for ship's purposes and make-up feed, can be produced more economically by using such partially expanded steam in the evaporators, than by using live steam direct from the boilers.

A supply of steam at a suitable pressure can be obtained, either by withdrawing steam from the main turbines, or by fitting steam-driven auxiliaries designed to exhaust at the pressure required. The latter is the system employed in H.M. ships.

Auxiliary engines, the exhaust steam from which is being used for feed heating, etc., are said to be on closed exhaust, from the fact that under these conditions any direct lead to the condensers from these engines is closed.

Where the quantity of auxiliary exhaust steam may exceed the amount required for feed heating and distilling, provision is sometimes made to admit the surplus exhaust steam to some or all of the ahead low-pressure turbines. It is more economical to use auxiliary exhaust steam in feed heaters or evaporators than to admit this steam to the main turbines, and in many modern ships closed exhaust connections to L.P. turbines are not fitted.

Where closed exhaust connections to the L.P. turbines are fitted, these can only be used for the disposal of surplus auxiliary exhaust when the vessel is steaming ahead. When the main engines are stopped, or going astern, surplus auxiliary exhaust is admitted to the main condensers.

167. Feed Heaters.—Feed water heaters may be of the contact,

or surface type. *Contact feed heaters* are fitted in the older ships, on the suction side of the feed pumps. The feed water is sprayed into a vessel, into which the auxiliary exhaust steam is admitted. The steam is condensed, and the temperature of the water is raised. The heated feed water has to be dealt with by the feed pumps, and trouble is likely to be experienced with these pumps if the feed water is heated to much above 160° F.

In all modern ships *surface feed heaters* are fitted, on the discharge side of the feed pumps. The feed water passes through tubes, which are surrounded by the auxiliary exhaust steam. From the feed heater the water passes direct to the boilers, and a higher feed temperature can be used than is possible with contact feed heaters.

168. Feed Heater Drain.—In the surface type of feed heater the water resulting from the condensation of the auxiliary exhaust steam does not mix with the feed water in the heater. The condensed steam leaves a surface feed heater through a drain valve. If the exhaust steam used is obtained from turbine-driven auxiliaries the drain water will not contain oil, and it may be passed into the feed water without risk of introducing oil into the boilers. In reciprocating engines oil is used for internal lubrication, and the exhaust steam from these engines will contain some oil. The quantity of oil present will be very small, if care is taken to use only the minimum quantity of internal lubricant. Oil should be used very sparingly on the piston rods of pumps, and the permeators on the slide chests should not be used without special orders. Even though these precautions are taken, it is desirable for the condensate from the exhaust steam of reciprocating engines to be passed through a *grease extractor*. The grease is removed by passing the water through a filtering material such as towelling, sponges, or coco-nut fibre, which is cleaned periodically. (*See* article 20.) This filtration will not be effective if the water is hot. It is therefore necessary to pass the drain water through a cooler before it enters the grease extractor.

169. Drain Cooler.—This fitting derives its name from the fact that it is used to cool the drain water from feed heaters. It is also used as a condenser for surplus auxiliary exhaust steam in harbour, when the main condensers are not available for this purpose, and no auxiliary condensers are provided.

A drain cooler resembles a small condenser, except that the steam side is open to the atmosphere through a breathing pipe. The cooling water is taken from the discharge side of the main circulator when at sea. A small water service pump is provided to pump sea water through the cooler in harbour. The fresh-water side of the cooler drains to the main feed tank by gravity.

170. Feed Heater Drain Pump.—Where the exhaust from turbine-driven auxiliaries only is used in a feed heater, there is no need to cool the drain water. It is more economical to introduce this hot water into the feed circuit on the suction side of the feed pumps. In modern battleships and cruisers a small electrically-driven pump is provided for each feed heater. This pump takes the drain water from a well at the bottom of the feed heater, and discharges it into a mixer on the suction side of the main feed pump. A float-controlled valve is fitted, to ensure that the pump shall not discharge water at such a rate that it runs dry. The feed heaters can also, if required, be drained by gravity to the main or reserve feed tanks.

171. Closed Exhaust to Turbines. Mention has been made in article 166 of the provision made in some ships for the admission of surplus auxiliary exhaust to the ahead turbines. The pressure in the auxiliary exhaust range must be greater than the stage in the main turbine into which the exhaust steam is to enter. The auxiliary engines are designed to exhaust against a maximum back pressure of 25 lb. per sq. inch. When steaming at high powers this is just sufficient to allow of closed exhaust steam entering the inlet end of the L.P. ahead turbines. Some of the older ships have in addition connections for closed exhaust about half-way along the H.P. ahead turbines. When steaming at low powers more work can be obtained from the auxiliary exhaust steam by putting it to the H.P. turbine than by entering it direct to the L.P. turbines. Screw-down non-return valves and strainers are fitted at each auxiliary exhaust connection on the main turbines. These valves will not lift off their seats until the pressure in the auxiliary exhaust system is greater than the pressure at the stage in the main turbine into which the steam is to enter.

In many modern ships all the auxiliary exhaust can be used in feed heaters and evaporators and connections to the turbines are not provided. Where these connections are provided they are to the L.P. turbines only, and adjustable spring-loaded valves are fitted which are set to lift if the pressure in the auxiliary exhaust system exceeds that required for feed heating and distilling.

Before admitting auxiliary exhaust to main engines care must be taken that the auxiliary exhaust system in the vicinity of the inlet is completely drained of water. Closed exhaust valves on turbines must be shut if the main engines are stopped or reversed. When such orders are expected, as when entering and leaving harbour, closed exhaust should not be used on the main engines.

172. Arrangement of Auxiliary Exhaust System.—In many ships all the steam-driven auxiliaries, except large electric generators

which have their own condensers, exhaust into a common auxiliary exhaust range. This extends throughout the machinery spaces, with branches to feed heaters, evaporators, condensers, drain coolers, and also in some ships to the main engines. A shut-off valve is fitted at each engine, or where the branch from each engine joins the range. Isolating valves are generally fitted where the range passes through the main bulkheads. Modern cruisers and battleships have very few, if any, reciprocating auxiliaries. Where only one or two reciprocating engines are fitted the exhaust from these is generally condensed in separate auxiliary condensers or coolers. In the latest destroyers a separate exhaust range is provided for the reciprocating auxiliaries. As in these ships the drain water from the heaters passes through a drain cooler and a grease extractor, both the clean and dirty exhaust is used in the feed heater. Surplus clean exhaust from turbo auxiliaries is admitted to the main condensers, while surplus dirty exhaust from reciprocating auxiliaries goes to the drain cooler.

173. Control of Closed Exhaust Pressure.—To prevent an excessive pressure in the auxiliary exhaust system, one or more large spring-loaded relief valves are fitted. These are known as *atmospheric exhaust or emergency relief valves.* They open automatically, and allow steam from the auxiliary exhaust range to pass through a waste steam pipe to the atmosphere, if the pressure rises to two or three pounds above the maximum working pressure. If the atmospheric relief valves lift, there will be a loss of fresh water. To prevent this loss surplus auxiliary exhaust can be relieved to the main condensers at sea, or to auxiliary condensers or drain coolers in harbour, through adjustable spring-loaded relief valves. A small spring-loaded valve, called a *sentinel valve,* is fitted on the auxiliary exhaust range in each engine room. These lift at a slightly lower pressure than the atmospheric relief valves, and warn the watchkeepers that the closed exhaust pressure is too high. Particular care must be taken that the atmospheric exhaust valves do not lift when men are working on the outside of the funnels near the waste steam pipe.

When a ship is in dry dock no circulating water is available for the condensers or drain coolers. If it is necessary to run any steam auxiliaries the exhaust must be put to the atmosphere. Provision is therefore made, either to open the atmospheric relief valves by hand easing gear, or to by-pass the exhaust round the atmospheric relief through a screw-down valve.

In ships fitted with steam capstan engines the auxiliary exhaust pressure must be released when the capstan is in use for working cables. As the auxiliary exhaust range is not completely air-tight, the pressure should not be allowed to drop below atmospheric

pressure when steam is on the main engines, or when the auxiliary exhaust is released to the main condensers.

Before raising the pressure in the auxiliary exhaust system, the speed of auxiliary engines, liable to be unduly slowed thereby, should be increased.

174. Draining of Steam and Exhaust Pipes.—All steam and exhaust pipes are sloped, so that any water from condensation shall flow to the ends of the pipe. Drain cocks are fitted on the valve boxes at the ends of pipes, so that any water which accumulates at these positions may be drained off. Drain cocks are also fitted on each side of isolating and bulkhead valves, as when these valves are closed a blank or dead end is created in which water collects. When any length of pipe is isolated the drain cocks should be kept open. Before commencing any repairs to an isolated portion of a steam or exhaust range it should be ascertained, by means of the drains, that the pipe does not contain steam.

Separators are commonly fitted on the auxiliary saturated range, to separate out water suspended in the steam. The steam passes round a baffle in the separator, which causes the water to fall to the bottom. On the drain from the bottom of each separator a *steam trap* is fitted. This is an automatic valve, which opens to allow water to pass through, and closes when all the water has passed and steam commences to escape. A by-pass is fitted round each trap, to allow for a more rapid discharge of water when necessary. Steam traps are also fitted at the more important drains on the main steam range and on superheater drains.

The drains from the cylinders and slide chests of reciprocating engines are led to the bilge, as the drain water will be contaminated with oil. Other drains are led into funnels, known as pig's ears, from whence the water passes to a main overflow or reserve feed tank. The open end of the drain pipe at the pig's ear prevents water being drawn up from the feed tanks into an empty pipe; also it can be ascertained if a drain pipe is discharging water or steam. A small grease filter is usually fitted on the drain pipe from the exhaust valve of a reciprocation engine.

A number of drains are commonly lead to each pig's ear, in modern ships, tally plates are fixed on the pig's ears to indicate from whence each drain pipe comes. The drains from a number of pig's ears join a common drain pipe, which discharges into one of the feed tanks below the water level. Drains from auxiliary engines at floor plate level are generally lead to the overflow tank, as this tank is lower than main or reserve feed tanks. *A valve is fitted on each drain where it enters a feed tank. These valves must be shut and lashed when a tank is opened for cleaning, to prevent the men in the tank being scalded.*

175. Water Hammer.—*It is of the utmost importance that, before opening out any valve on a steam or exhaust range, the pipes should be thoroughly drained.* If there is any water in the pipe, on opening the valve, the water may be caused to travel along the pipe at high velocity. What is known as water hammer will result, when this water reaches a valve box where the steam changes its direction of flow. The valve box may be cracked or the cover carried away by the blow from the water.

Particular care must be taken when opening out steam on a portion of a steam range which has been isolated. Before commencing to open out, watchkeepers on running machinery should be warned to keep separators drained and to open drains on engines and pipes, if necessary. Drain cocks on the pipes should be opened cautiously, as a sudden opening may cause water hammer. When the pipes are clear of water the isolating valves should be just cracked off their seats. A considerable period, depending on the size and length of the pipe which has been isolated, is to be allowed for warming through.

The steam pressure in this length of pipe must be allowed to rise very slowly, and the pipe must be kept drained. When the pressure is the same on each side of the valve, and all the water has been drained off, the valve may be opened to its full extent. This must be done slowly, as the direction of flow of steam to running machinery may be altered, and water lying in some remote part of the system may be dislodged by this change in the flow of steam.

CHAPTER XII.

CONDENSING PLANT AND FEED WATER CIRCUITS.

176. Condensers.—It is necessary to condense the exhaust steam in marine engines, in order to obtain a supply of feed water for the boilers (the boilers of a destroyer steaming at full speed require about 200 tons of water an hour), also exhausting into a condenser, in which a good vacuum is maintained, materially increases the efficiency of the engines. The better the vacuum in the condenser the lower will be the fuel consumption, and also the greater will be the maximum power that can be obtained. The condensing plant fitted in H.M. ships is designed to produce a vacuum of 28 inches of mercury, with the barometer at 30 inches, when steaming at full power, with a sea temperature of 60° F. The reading of the vacuum gauge will rise and fall with the barometer. An increase in the sea water temperature will reduce the vacuum by about $\frac{3}{4}$ inch for a rise of 10° F., and similarly a drop in sea temperature will improve the vacuum.

In modern ships the main condensers are placed underneath the L.P. turbines. The weight of the condenser is taken either wholly by the L.P. turbine, or partly by the turbine and partly by spiral springs under the condenser. The weight must be taken on chocks if the top half of L.P. turbine casing is to be lifted; if this is not done, the weight of the condenser will distort the lower half of the L.P. casing.

It was the practice to fit in cruisers and larger ships one or two small auxiliary condensers, to take, either all the exhaust from auxiliary machinery in harbour, or such portion of this as is not used in the evaporators. In modern ships, auxiliary exhaust is used for feed heaters, in harbour as well as at sea. Any surplus auxiliary exhaust when in harbour is condensed in a drain cooler.

The modern condenser is roughly semi-circular in cross section. The U-shaped portion is known as the shell and is built of steel plate. The top is open, and is fitted with a flange which is bolted to a similar flange on the bottom of the L.P. turbine casing. A brass tube plate is bolted to flanges at each end of the shell. Holes are drilled in the tube plates to receive the ends of the tubes through which the sea water passes. The tubes are of brass in the older vessels, but in modern ships cupro-nickel tubes are generally fitted, as these are less liable to become perforated by corrosion. A water-tight joint must be made where the ends of the tubes pass through the holes in the tube plates, and at the same time the tubes must be

free to expand and contract. The holes in the tube plates are enlarged for a depth of two-thirds of the thickness of the tube plate and tapped to take a screwed ferrule. In the older ships, a linen gromet, soaked in boiled linseed oil, is fitted over each end of the tube inside the recess in the tube plate, and ferrules are then screwed in to compress these gromets. The gromet forms a watertight joint round the tube, and leaves the tube free to expand. In modern ships, Crane's condenser tube packing is fitted. At the sea inlet end the tube is fixed in the tube plate by screwing a ferrule onto a soft brass conical washer, fitted over the tube in the recess in the tube plate. Screwing up the ferrule forces the conical washer on to a fibre ring, fitted at the bottom of the recess, and also closes in the conical end of the washer so that it grips the tube. At the outlet end the tube is free to expand through a number of fibre and metal foil packing rings, which are caulked into the recess in the tube plate.

A number of stay rods are fitted between the tube plates, to prevent distortion of these plates by the difference in pressure between the steam and water sides of the condenser. Diaphragm plates, with holes through which the tubes pass, are fitted inside the shell; these support the tubes between the tube plates. A large cover is fitted over the tube plate at each end, to form pockets through which the sea water passes to enter and on leaving the tubes. Main condensers are usually single flow, that is, the sea water enters through a large branch in the cover at one end and leaves through a branch in the cover at the other end. In double flow condensers the sea water enters and leaves at the same end of the condenser, flowing first through the tubes of the bottom half and back through the top half. The covers are made of gunmetal in modern ships, but in some of the older ships cast steel covers are fitted. Steel covers are coated with india-rubber or a bitumastic compound to protect the steel against the action of the sea water. Steel protector slabs are fitted in the spaces between the tube plates and the covers, in some ships at the inlet end only and in others at both ends. The galvanic action, between these steel plates and the tube plates and tube ends, causes the protector plates to be attacked and to some extent protects the tube plates and tubes. The protector plates must be renewed about every six months. Inspection doors are fitted on the covers to give access to the protector slabs, and to allow of the tube plate and tubes being cleared of weed and other obstructions.

The fresh water, resulting from the condensation of the exhaust steam, falls to the bottom of the condenser, from whence it flows by gravity to the suction side of the air pump or extraction pump. In some condensers strainers are fitted to prevent any foreign matter being carried to the pump. Water-level indicators are fitted on

the condenser shell, to show the height of fresh water in the condenser.

177. Testing Condensers.—It is of the utmost importance that there shall be no leakage between the sea-water side and the fresh-water side of a condenser. The method of detecting salt in the feed water is dealt with in article 19. In ships with water-tube boilers a leak in a condenser should, if possible, be dealt with immediately. If this is not possible the main engine concerned should be allowed to trail and the condensate from the defective condenser discharged to the bilge.

A leak in a condenser can be located, either by what is known as the Canterbury test or by applying a water-pressure test to the steam side. In the Canterbury test an air pressure of not more than 10 lb. per sq. inch is put on the steam side of the condenser. The sea-water side is kept flooded up to the top inspection doors on the covers, and the leaking tube located by the air bubbles. The defective tube is plugged at both ends, until it can be removed for examination and report. Although the Canterbury test is a quicker method of detecting a perforated tube and can be more conveniently carried out at sea, it may not be effective in the cases where the contamination of the feed water is due to a number of very small leaks from ferrules which require tightening. Such leaks can best be detected by emptying the sea-water side, filling the steam side with warm fresh water. When the tube plates are dry, even the smallest of leaks can be detected by admitting air or closed exhaust steam to the condenser above the surface of the water. As in the case of the Canterbury test, the pressure must not exceed 10 lb. per sq. inch.

When a condenser is being tested at sea the turbines in connection with this condenser must not be allowed to revolve during the time that the vacuum is broken, or overheating of the blades may result. The provisions made for disconnecting turbines and preventing propeller shafts from revolving are described in articles 140 and 141.

178. Condenser Auxiliaries and Feed Systems.—Circulating pumps must be provided to circulate sea water through the tubes of a condenser, and the fresh water produced by the condensating steam in the condenser must be pumped out. Also in order to maintain the vacuum, provision must be made to withdraw from the condenser any air which enters with the exhaust steam or through leaky joints and glands on the condenser shell or fittings.

In the older ships, and also in some of the modern small vessels, what is known as an *open feed system* is used. A large reciprocating pump, called an air pump, is used to withdraw both water and air from the condenser. Some of the air dissolves in the water, and

the remainder is allowed to escape to the atmosphere. The water passes to a tank known as the main feed tank, from which the feed pumps take their suction. The weight of water in the boilers depends on the rate of evaporation (*see* article 33). When the speed of the main engines is reduced less steam is being condensed in the main condensers, but the boilers require for a short period an increased quantity of feed water. The extra feed water required must be available in the main feed tanks, which should therefore be kept nearly full when steaming at high speeds. Similarly, the main feed tanks must accommodate the surplus feed water when the speed of the main engines is increased.

To prevent loss of feed water when the speed of the main engines is increased, overflow feed tanks are fitted, into which the main feed tanks overflow if they become full. Water can be returned to the feed system from the overflow tanks, either by pumping it into the main or reserve feed tanks by means of a small pump fitted for transferring feed water, or by opening a valve, called the supplementary feed valve, which allows the vacuum in the condenser to draw water out of the overflow tank. In cruisers and larger ships a reserve of feed water is carried in the reserve feed tanks in the boiler rooms. If needed, this water must be pumped out by the auxiliary feed pumps.

In destroyers most of the reserve of feed water is carried in the overflow tanks in the engine room, and the auxiliary feed pumps are provided with a suction from this tank. This tank is larger than that fitted in cruisers and is often called the reserve feed tank. Some destroyers carry additional boiler water in tanks built into the wings of the boiler rooms. The water in these tanks will run down by gravity to the overflow or reserve feed tank in the engine room through the auxiliary feed pump suction. Water can normally contain a certain quantity of air in solution, but if the water is boiled the air in solution is driven off. In the open feed circuit the condensate is in contact with air in the air pump and in the feed tank. The boiler feed water will therefore contain air. This air will pass over with the steam to the condenser, and will have to be removed by the air pump to maintain the vacuum.

In the *closed feed system*, which is fitted in nearly all modern ships, the condensate and the air are withdrawn from the condenser separately, the former by a rotary pump known as an extraction pump, and the latter by an air ejector. The condensate is passed direct to the suction side of the feed pump, and thus does not come into contact with air. The provision made to deal with the variation in the quantity of water required in the boilers at different rates of steaming is dealt with in article 182.

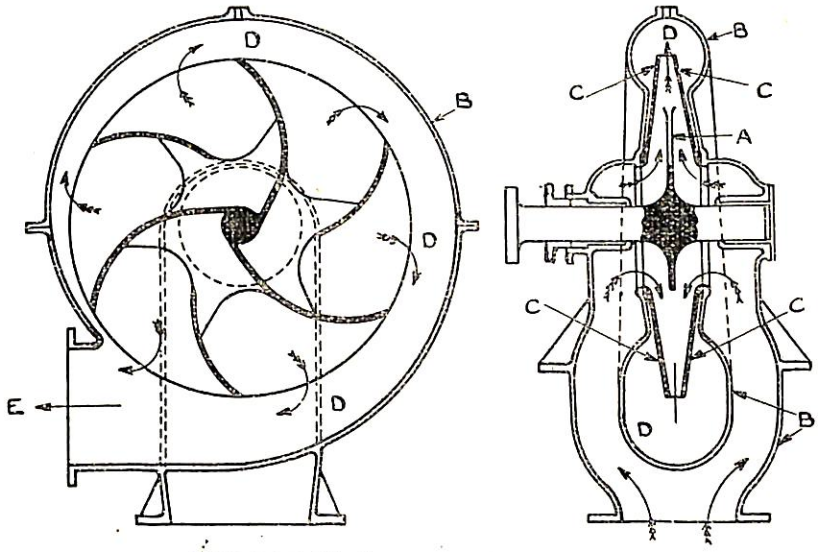
The closed-feed system operates only when steam is on the main engines and the main condensers are in use. A de-aerator is

fitted in cruisers and larger vessels to provide feed water free from air in solution when in harbour.

If, in a destroyer, it is required to keep steam for auxiliary purposes only, an open-feed circuit is used. The exhaust from turbo auxiliaries not required for feed heating or distilling is condensed in a main condenser. A vacuum is not maintained in the condenser, and the condensate is pumped out by an auxiliary feed pump through a stationary extraction pump.

179. Circulating Pumps and Valves.—Sea water is circulated through the condenser by a centrifugal or axial flow rotary pump. Fig. 29 shows two sections through a centrifugal pump. The impeller A revolves inside the casing B. The bottom of the casing is in communication with the sea through the main inlet pipe, on which is fitted a large valve, known as the main inlet valve. As the pump is situated at a lower level than the level of the sea outside the ship, sea water will flow in and fill the pump casing, air being released through a cock on the top of the casing. The impeller consists of two circular plates CC, between which are a number of curved vanes. Due to the rotation of the impeller, a centrifugal force is exerted on the water contained between the two plates CC. This force causes water to flow into the annular port around the

FIG: 29.



CENTRIFUGAL CIRCULATING PUMP.

centre of the impeller, and to be discharged from the circumference into the space D and thence through the discharge pipe E.

In the axial flow type of circulating pump, fitted in modern ships, the impeller is situated inside the main inlet pipe. The impeller resembles a propeller, and its rotation causes a flow of water through the pipe. By sloping the inlet pipe, it can be arranged that the motion of the ships in the ahead direction will cause a flow of water through the inlet pipe. The axial flow impeller has the advantage that it will offer very little resistance to this natural flow. With this arrangement it is only necessary at cruising speeds to supply sufficient steam to the circulating engine to keep the engine warm and the impeller trailing.

In the older ships the circulating pumps are driven by a steam reciprocating engine. In practically all modern ships turbines are fitted to drive the circulating pumps through gearing. Running the circulating pumps at a higher speed than is necessary will not produce an improvement in the vacuum, and materially increases the steam consumption of the engine which drives the pump. In a few ships an electric motor is fitted to each circulating pump in addition to the turbine drive. These motors can be connected by means of a clutch, when only low speeds are required.

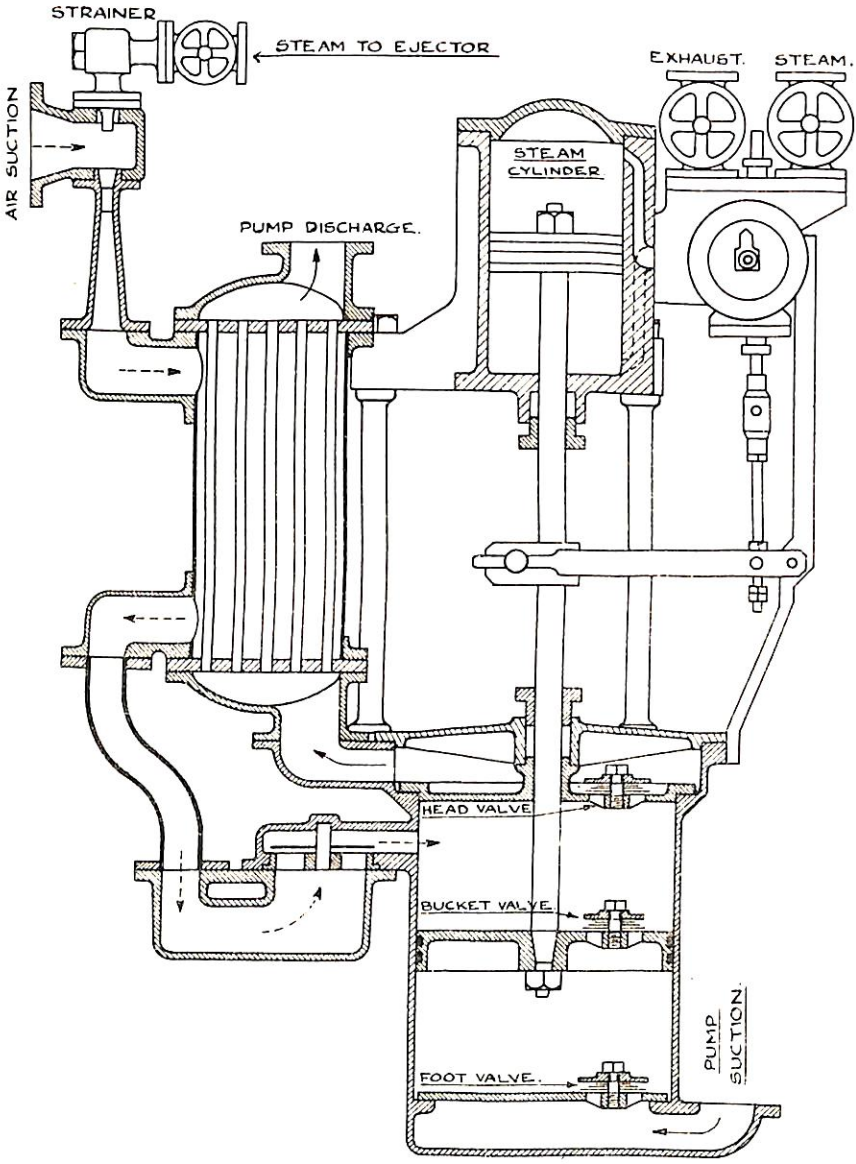
After passing through the condenser the circulating water passes overboard through a main discharge valve. Both the main inlet and main discharge valves must be kept closed in harbour when the main condensers are not in use.

Provision is made so that the main circulating pumps can be used to pump water from the engine room in case of emergency. A branch is lead to the bilge from the suction side of each circulating pump, and a large screw down non-return valve is fitted at the end of the branch. By opening this valve and shutting the main inlet valve, water may be pumped from the engine room, through the condenser and overboard.

180. Gratings and Weed Traps.—The sea often contains seaweed, jelly fish and other solid matter which, if precautions are not taken, will choke pumps, condensers, etc. All holes in the bottom of the ship through which sea water is drawn are fitted with gratings. Seaweed is liable to be more troublesome in smaller vessels, on account of their shallow draught. In these vessels, in addition to the grating over the main inlet, a *weed trap* is fitted on the main inlet pipe inside the ship. This consists of a box containing a perforated plate, which can be removed and cleaned after shutting the main inlet and discharge valves.

Weed clearing ejectors are provided in cruisers and larger vessels, for clearing the main inlet gratings if these become choked with seaweed or other solids. With the main inlet valve closed, a steam

FIG: 30.



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PARAGON AIR PUMP.

ejector can be brought into use, which causes a flow of water out through the inlet grating.

181. Air Pump.—An air pump is a vertical single-acting reciprocating pump with three groups of non-return valves. The valves are discs, cut from special bronze plate about one-sixteenth of an inch in thickness, and are arranged as shown in Fig. 30. When the plunger moves up air and water are drawn through the foot valves at the bottom of the pump barrel. On the down stroke this volume of air and water passes to the upper side of the plunger, through the bucket valves in the plunger. On the following up stroke the bucket valves close, so that the air and water above the plunger are lifted and pass out of the pump through the head valves. During the same stroke a further volume of air and water is drawn into the barrel below the plunger.

In some small ships propelled by reciprocating engines the air pump is actuated by a rocking arm from the main engine. While the engines are being warmed the condenser is kept pumped out by a small steam-driven pump, or by allowing the water to drain to the bilge through a non-return valve at the bottom of the condenser. If the main engines are started with a lot of fresh water in the condenser the air pump may be damaged.

In other ships with reciprocating engines, and in all turbine-driven vessels, what are known as independent air pumps are fitted. These pumps are not connected to the main engines, each pump having its own steam cylinder.

One pound of steam at condenser pressure will occupy about 300 cubic feet. While a turbine can take full advantage of expansion of the steam right down to condenser pressure, it would not be advantageous to make the L.P. cylinder of a reciprocating engine large enough to achieve this. The maintenance of a good vacuum became of greater importance with the introduction of the turbine, changes have been made in condenser design and new types of air pumps introduced.

Early turbine-driven vessels are fitted with the *Weir's dual air pump*. Each unit consists of a single-cylinder steam engine which operates two reciprocating pumps. The pump directly under the steam cylinder is known as the wet pump, and takes its suction from the bottom of the condenser. The other pump, which is operated by a rocking arm, is known as the dry pump. This pump draws air and vapour from the condenser, and discharges into the barrel of the wet pump through a non-return valve. The quantity of air which the dry pump can handle is increased by admitting a jet of cold water into suction pipe. Some of the vapour is condensed by this jet and the air is cooled. The cooling jet is provided by allowing water from above the head valves of the dry pump to flow through

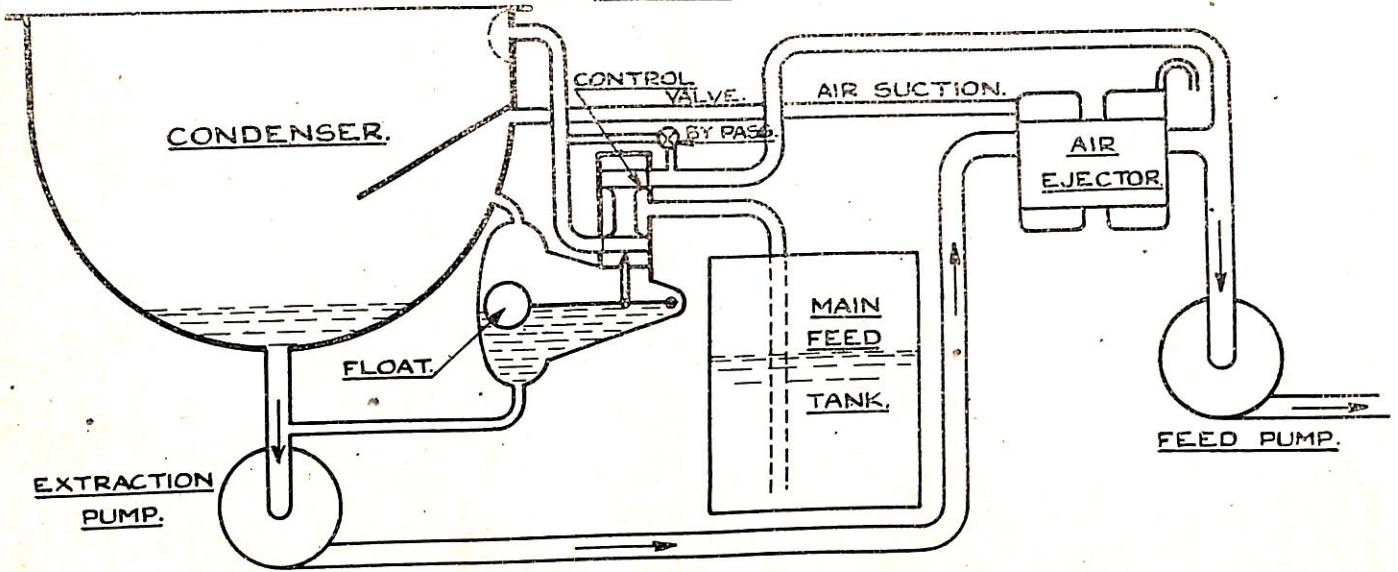
a cooler back to the suction. To ensure a supply of cooling water on starting the pump, a small pipe with a cock is provided from the wet pump to the dry pump.

Most modern turbine vessels, which are not fitted with a closed feed system, have *Paragon air pumps*. The pumps fitted in small vessels have one barrel, as shown in Fig. 30. In larger vessels, twin pumps, with a common suction and with one steam cylinder, are fitted. The pump withdraws the condensate through a suction pipe from the bottom of the condenser. Air and vapour are withdrawn by an air ejector from a point higher up the condenser. A jet of steam issuing at high velocity from a nozzle is directed into the mouth of a conical tube, called a diffuser. Air and vapour are drawn into the diffuser by the jet from the nozzle. The steam and air from the ejector pass into a small condenser, where the steam is condensed and the air cooled. The air, together with the water from the steam condensed in the ejector condenser, pass through a non-return valve into the barrel of the pump. On the twin pump units only one ejector is fitted, and the air discharge pipe from the ejector condenser is divided into two branches, one to each pump. In a few ships sea water is circulated through the ejector condenser, but the usual arrangement is that shown in Fig. 30, where the fresh water discharged by the pump passes through the tubes of the ejector condenser. When the main engines are stopped, or running slow, the quantity of steam being condensed on the main condenser will not provide sufficient cooling water for the ejector condenser. In some ships provision is made to admit water from the main feed tank to the main condenser, in order to keep the ejector condenser cool when manoeuvring, but the general practice is to shut steam off the ejector under these conditions.

182. The Closed Feed System.—It has been pointed out in Article 16 that air in the feed water is one of the causes of corrosion in boilers. The aim of the closed feed circuit is to supply the boilers with feed water which contains no air in solution. Baffles are fitted in the condenser, to provide a long path through the tubes to the air ejector suction, and at the same time to allow the water formed by the condensation of the steam to fall as directly as possible to the bottom of the condenser. The condensate, which is thus collected at as high a temperature as possible, is supplied to the boilers through a closed circuit, so that no opportunity is presented for the absorption of air.

Fig. 31 shows a modern closed feed circuit. The extraction pump maintains a pressure of 20 to 40 lb. per square inch on the suction side of the feed pump. The feed pump increases the pressure in the feed circuit to about 100 lb. per square inch above the working pressure in the boilers.

FIG: 31.



CLOSED FEED CIRCUIT.

While steaming at a steady speed, if no steam or water were lost from the circuit, the water produced by the condensation of steam in the condenser would be just sufficient to maintain the water level in the boilers at a uniform height. In practice, there is a loss due to draining etc., and also provision must be made for the difference in the weight of water in the boilers at different powers. A small reserve of water can be accommodated in the bottom of the condenser, but this will not be sufficient to meet the requirements. It is necessary, therefore, to arrange, that on reducing speed additional feed water is drawn into the circuit, and on increasing speed water is passed out of the circuit to prevent the condenser being flooded. When needed, water is drawn into the circuit from the feed tank by the vacuum in the condenser. Under the low-pressure conditions in the condenser water boils at about 100° F. Any air contained in the water drawn into the condenser will pass out of solution, and will be extracted by the air ejector. Excess water is passed out of the circuit to the main feed tank from the discharge side of the extraction pump. The admission of water to, and discharge from, the circuit, are controlled by the level of water in the bottom of the condenser. A float, in a chamber which is in communication with the condenser, operates a small needle valve, which controls the position of a piston type valve known as the control valve. Pressure from the discharge side of the extraction pump is used to cause the control valve to follow the needle valve. The control valve may be above the float, as shown in Fig. 30, but in some ships a different arrangement is fitted with the control valve below the float. If the level of water in the condenser falls, the float and the needle valve drop, the control valve follows, and a passage is opened between the feed tank and the condenser. Water is admitted to the condenser until the float restores the control valve to its mid position. If water is collecting in the condenser at a greater rate than it can be taken by the feed pump, the float rises. The needle valve now causes the control valve to lift, and allows water to pass from the discharge side of extraction pump to the main feed tank, until the level in the condenser is restored to normal. In the earlier closed feed arrangements, two floats are fitted in the float chamber at slightly different levels. The lower float controls a make-up feed valve through which water is admitted to the condenser, while the upper float controls an overflow valve through which water is discharged to the feed tank. The speed of the feed pump, being controlled by a pressure governor, maintains a constant feed pressure at the boilers. An overspeed governor is also fitted, to shut steam off the pump, should the revolutions exceed the maximum for which the pump is designed. The extraction pump is controlled by a constant speed governor, so that it is always running at such a speed that it can instantly meet the maximum demand

of the feed pump. Should the feed pump run short of water, it will overspeed, and the governor will trip the steam valve. In destroyers there is a branch from the suction side of the feed pump to a screw-down non-return valve on the main feed tank. At sea the hand wheel of this valve is screwed back, so that the valve is free to open. As long as the extraction pump discharge pressure is greater than the pressure due to the head of water in the feed tank, the valve will not open. Should the extraction pump discharge pressure drop momentarily, the feed pump can draw water from the main feed tank. In harbour, when the extraction pump is not running, this non-return valve is kept shut. An auxiliary feed pump can then be used to pump out the condensate through an extraction pump. A sluice valve is fitted on the feed tank, to allow of the non-return valve being examined without emptying the tank. A similar emergency suction from the main feed tank is being fitted in the new battleships. The steam valves of both pumps must be wide open, the control of the pumps being left to the governors. Should a pump stop through the overspeed governor tripping, the hand wheel of the steam valve must be turned into the shut position, before the governor can be reset and the pump restarted.

Where, as in the arrangement illustrated, the air ejector is cooled by the extraction pump discharge, a small by-pass valve is fitted to provide a circulation through the cooler, when the main engines are stopped and the feed pump is taking very little water.

The simple system described consists of a unit of one condenser, one main engine and one or more boilers supplying steam to this engine. Actually, there will be two, three or four sets of main engines in a ship, and only when steam is required for full speed will all boilers be alight. The number of main feed pumps used will depend on the number of boilers alight. Cross connections are provided, so that the extraction pump of any unit can supply water to any feed pump. When steaming at low powers it is desirable to reduce the number of steam auxiliary engines in use, as otherwise there will be more exhaust steam from these engines than is required for feed heating. In destroyers one extraction pump can be used for both condensers when the main engines are required to develop less than half their full power. In cruisers, in addition to the one steam-driven extraction pump for each condenser, an electrically-driven pump is provided for each pair of condensers. These electrically-driven pumps are used instead of the steam pumps at low powers.

183. Extraction Pump.—These pumps are of the centrifugal type. The pump chamber must be below the bottom of the condenser, in order that the condensate shall flow by gravity to the pump. With underslung condensers it is necessary to fit vertical

pumps with the pump chamber at the bottom. Each pump is driven, either by a single-wheel impulse turbine, or by an electric motor. On account of the low-pressure conditions on the suction side, extraction pumps have two impellers, and these should not run at a high speed. By employing a high-speed turbine to drive the impellers at medium speed through gearing, the steam consumption is reduced. Geared extraction pumps are fitted in destroyers, but in larger ships, where electric pumps are provided for cruising speeds, direct-drive extraction pumps with lower speed turbines are fitted.

A governor, operating a double-seated valve on the steam supply, controls the speed of the pump. An adjustment is provided on this governor, so that, when two extraction pumps are supplying the same feed pump, the outputs of the pumps can be levelled. It will be necessary for the extraction pump further from the feed pump to be run at a slightly higher speed than the other. There is also an emergency governor, to trip the steam valve of the pump in the event of overspeeding.

In a geared extraction pump a small pump is fitted to provide oil to the gearing and to the turbine and gear-wheel spindle bearings. The lubricating oil is passed through a cooler and through an Auto-klean filter. In the Allen's extraction pump a type of governor is fitted in which oil pressure is used to operate the valve which controls the speed ; to start this type of pump it is necessary to pump up an oil pressure by means of a hand pump fitted for this purpose. In the direct-drive pumps an oil bath, as described in article 157, is provided for each of the two roller bearings on the turbine spindle. A grease cup is fitted to the bearing on the pump spindle in both geared and direct-drive pumps. A shut-off valve is fitted on the suction of each pump, and a screw-down non-return valve on the discharge. A small pipe is led from the discharge side of each extraction pump to the gland on the suction valve, to provide a water seal and prevent air leaking into the system. The glands on the spindles of the extraction pumps must not be screwed up tight, or they will become hot and the spindle will be worn. A slight leakage of water is allowed past the packing, and this water is led through a small pipe to the overflow feed tank. Should the suction valve leak on a pump which is not running, air might be drawn into the system through the gland of the pump. To prevent this happening, a small by-pass is provided around the non-return discharge valve, so that a pressure can be kept in the pump when it is not in use.

184. Air Ejector. The air ejector fitted to the Paragon air pump, and described in article 181, is what is known as a single-stage ejector. Such an ejector is not capable of producing a high vacuum

if discharging against atmospheric pressure. With a closed-feed circuit either two-stage or three-stage ejectors are used.

In a two-stage ejector the first-stage ejector withdraws air from the condenser and compresses it to about half atmospheric pressure. The air, together with the steam from the first-stage nozzle, then passes through the tubes of the first-stage cooler. The steam condenses in the cooler, and the water drains to the condenser. The air passes to the second-stage ejector, where it is compressed to atmospheric pressure. The steam and air then pass through the tubes of the second-stage cooler. This portion of the cooler, being under atmospheric pressure, is drained to the feed tank. The air passes to the atmosphere through a non-return plate valve, known as the vacuum retaining valve. This valve is fitted to prevent air passing back through the ejector into the condenser, should the ejector fail to function through a jet becoming choked or the supply of steam being insufficient. The first-stage and second-stage coolers are enclosed in the same casing. The cooling water flows around the outside of the tubes of both coolers, and also cools the diffusers into which the air is drawn and compressed by the jet of steam from the nozzle.

The lower the temperature of the cooling water the more efficient will be the ejector. In destroyers sea water is circulated through the ejector coolers from a branch on the discharge side of the main circulators. In cruisers and larger vessels the condensate discharged by the extraction pump passes through the coolers. By this means the heat from the steam used in the ejectors is recovered. The condensate is not as cold as sea water, and it is necessary to adopt a more efficient form of cooling, or to fit a three-stage ejector. The modern practice is to fit a form of two-stage ejector in which, in addition to the first and second-stage surface coolers, a jet cooler is incorporated between the two stages. The air, and any steam leaving the first-stage surface cooler, pass through a spray of water from the extraction pump discharge.

In all air ejectors a strainer is fitted on the steam supply to prevent pieces of dirt or scale choking the nozzles.

In destroyers one air ejector is provided for each condenser, and a cross connection is fitted, so that up to half power one ejector can be used for both condensers. In cruisers, in addition to the air ejector for each condenser, one spare is generally fitted per two condensers. In battleships there is a spare ejector for each condenser.

185. Feed Pumps.—As explained in article 28, the main feed pumps are used to feed the boilers when steam is on the main engines. These pumps take their suction from the main feed tanks, or from the extraction pump discharge when a closed feed

system is fitted. A suction from the reserve feed tank is not usually provided for the main feed pumps.

The auxiliary feed pumps are used as stand-by at sea, and to feed the boilers in harbour where a special harbour service feed pump is not fitted. The auxiliary and harbour service feed pumps can take water from the main feed tanks, the reserve feed tanks, and also from the extraction pump discharge in modern ships with a closed feed system. Where a de-aerator is fitted these pumps can also be supplied by the de-aerator extraction pump. In destroyers there is a common suction for all auxiliary feed pumps from the reserve or overflow tank in the engine room, but in larger vessels the reserve feed tank suction of auxiliary feed pumps is only from the tanks in the boiler room in which the pumps are situated.

In all classes of ships with an open feed circuit, except trawlers and similar small vessels, independent feed pumps are fitted in the boiler rooms. In small vessels with reciprocating main engines and cylindrical boilers the main feed pump is generally driven from the main engine, and an auxiliary independent feed pump is also fitted in the engine room.

In ships with a closed feed system the main feed pumps are invariably turbo pumps, and are generally fitted in the engine room. The auxiliary pumps are fitted in the boiler room and may be either turbo or reciprocating pumps.

The independent reciprocating feed pumps of practically all H.M. ships are of the Weir's type described in article 127.

The Weir's turbo feed pump is a single-stage centrifugal pump, directly coupled to a single-wheel impulse turbine. The spindle carrying the turbine wheel and impeller revolves in two bearings, which are fitted with ring lubrication. Sea-water cooling is fitted to the top half of these bearings. The pump is designed so that when discharging against a pressure there will be a hydraulic thrust on the impeller, which balances the axial thrust of the steam on the turbine blades. If the pump is run with no pressure in the feed-discharge system the discharge valve must be throttled down, to maintain a pressure in the pump. A collar is provided on the spindle at each end of one of the bearings, to take any unbalanced thrust when starting the pump.

A leak off is taken from the pump gland to provide a small circulation of water to keep the gland cool. This leak off is led to a main or reserve feed tank, and a valve or cock is fitted on this leak-off pipe.

Some circulation of water through the pump chamber of a turbo pump is necessary to prevent the pump overheating. Auxiliary feed pumps may, when in use as stand-by pumps or for testing boilers, be running without discharging any water. These pumps are therefore fitted with a by-pass or bleeder connection, which

allows a small quantity of water to pass from the discharge side of the pump to a main or reserve feed tank. When an auxiliary feed pump is running as stand-by, the water from the by-pass should be returned to the tank from which the pump is taking its suction.

As in the case of other turbo auxiliaries the steam valve is spring loaded, and is tripped by an emergency governor if the pump should overspeed. Between the steam valve and the nozzle box is the double-seated valve of the constant-pressure governor. This valve is operated by a spring-loaded plunger, on which pressure from the discharge side of the pump acts. The spring tends to open the valve, and the feed discharge pressure to close it. The valve therefore admits the quantity of steam required to maintain a constant discharge pressure. An auxiliary or overload valve is fitted on the nozzle box, to enable the power of the turbine to be increased if necessary when steaming at full speed.

186. Air Separator and Priming Pump.—The auxiliary and harbour service feed pumps must be capable of taking water from the reserve feed tanks. If the level of water in the reserve feed tank is below the level of the pump, the pump chamber and the suction pipe will contain air if the pump has not been in use for some time. A reciprocating pump will quickly exhaust this air, but a turbo pump will not do so, and will therefore fail to pick up a suction unless means are provided to exhaust the air in the pump. In ships with centrifugal auxiliary and harbour service feed pumps, where the water level in the reserve feed tanks may be below these pumps, an air-separating chamber and a small electrically driven pump, known as a priming pump, are fitted in each boiler room. The air-separating chamber is fitted slightly higher than the auxiliary and harbour service feed pumps, and a branch is led from the the bottom of the chamber to each of these pumps and to the reserve feed tank suction pipe. The priming pump takes its suction from the top of the air separator, and by exhausting the air draws the water up to such a height in the chamber that it is above the feed pumps. To prevent water reaching the priming pump, on the suction to this pump is fitted a valve, which is closed by a float when the water in the chamber reaches the required level. The priming pump is kept running, and by means of a gauge glass on the air separator it can be ascertained that the water is maintained at the correct height.

187. De-aerator.—In ships with a closed feed system, which keep steam in harbour, a de-aerator is fitted to provide de-aerated feed water for the boiler in use for auxiliary purposes. De-aerated water is not generally used for the low-pressure auxiliary boiler fitted in some ships. Where a de-aerator is fitted, de-aerated water

is also used for pumping up boilers for preservation or after cleaning.

A de-aerator consists of a vessel, in which a vacuum can be maintained by means of an air ejector which discharges to the drain cooler. Half-way down the vessel are a number of tubes, through which auxiliary exhaust steam can be passed. Water is raised from a main feed tank or overflow tank by the overflow tank or feed transfer pump, and sprayed into the top of the de-aerator. This water, falling over the tubes heated by auxiliary exhaust steam, is raised to the boiling point. Any air in solution in the water is driven off and discharged by the air ejector.

The de-aerated water falls to the bottom of the de-aerator, from whence it is withdrawn by a small centrifugal pump, known as the de-aerator extraction pump, and supplied to the suction side of the auxiliary or harbour service feed pumps. In modern ships, where the auxiliary or harbour service feed pumps are fitted with a suction from the closed-feed system, the de-aerator extraction pump discharges to this system. In the older ships the de-aerated water is discharged to the auxiliary feed pump suction from the main feed tank. A valve, controlled by a float in the de-aerator, is fitted on the pipe through which the feed water enters the de-aerator. This valve automatically controls the rate of supply, so as to maintain a constant head on the suction side of the de-aerator extraction pump.

To start up a de-aerator, first see that cooling water is circulating through the drain cooler. Open the valve on the ejector discharge to cooler, put steam on the ejector and adjust pressure to 125 lb. per square inch. Open the valves between the feed transfer pump and the feed tank from which water is to be drawn. Start up the pump, and open the necessary valves to allow water to be discharged to the de-aerator. Open the suction valve of the de-aerator extraction pump and start this pump. Now open the discharge valve to the harbour service or auxiliary feed pump suction. As soon as water is passing to the feed pump, open the drain to the de-aerator heater, and put steam on the heater. The outlet temperature from the de-aerator should be about 160° F., which is the boiling point of water under a vacuum of 20 inches. When shutting down a de-aerator the heating steam should be shut off first.

A slightly different arrangement will be found in the first ships fitted with de-aerators. In the Kent class cruisers, below the de-aerator extraction pump and driven by the same motor is a lift pump for raising the water from the feed tank. In the Norfolk class the vacuum in the de-aerator is used to raise the water, and the fresh water or overflow tank pump is used to pump the water from the de-aerator to the feed pump.

To ascertain the degree of de-aeration achieved, the quantity of oxygen in solution in the water is measured by a chemical test

known as the Winkler test. A de-aerator is specified to produce a certain quantity of de-aerated water per hour, with not more than 0.05 C.Cs. of oxygen per litre. The degree of de-aeration will probably fall off if the designed output of the de-aerator is exceeded.

188. Pumping up Boilers.—To reduce the corrosion in boilers when not in use, they should be pumped up with de-aerated water in ships having a de-aerator. If steam is on the main engines de-aerated water may be taken from the closed-feed system. Permission must be obtained from the engineer officer of the watch before taking water from this system, as steps will have to be taken to replace the water removed from the main feed tanks. If de-aerated water is sprayed into a boiler containing air through the internal feed pipes, oxygen from the air will be dissolved in the water. Where possible boilers should be pumped up through the running-down valves and superheater drains.

In most modern ships arrangements are fitted to exhaust most of the air from a boiler before commencing to pump it up, and to maintain a vacuum above the water level while the boiler is being filled. Pipes from the air cocks on the steam drum and superheater headers join into a common pipe, which terminates in a hose connection. By connecting a hose from this connection on any boiler to some system in which a vacuum can be produced, the air can be exhausted from this boiler. A sight glass is fitted on the pipe from the air cocks, in order that it may be ascertained when the boiler is full.

The most general arrangement is to connect the pipe from the air cocks to the priming pump of a centrifugal F and B pump. A flow of water should be maintained through the centrifugal pump, by opening the suction from the sea and the discharge overboard. In some ships the air ejector of the de-aerator may be used, while in others provision is made to connect the air cocks to a main condenser.

CHAPTER XIII.

EVAPORATORS, STEERING GEAR AND CAPSTAN.

189. Evaporators.—Fresh water from the mains must not be used in water-tube boilers, on account of the scale that would be formed by the solids in solution in this water. Distilled water must therefore be made for boiler feed, and is also used by the ship's company when a supply of suitable water for drinking and washing cannot be obtained from shore.

Distilled water is made by boiling sea water in a vessel called an evaporator, and condensing the steam formed in a small surface condenser known as a distiller. In the lower portion of the evaporator are a number of coils of copper tubing, into which either live steam from the boilers or closed exhaust steam is admitted to heat the water. The evaporators fitted in H.M. ships are generally designed for a maximum pressure of 25 lb. per square inch in the coils, and a relief valve is fitted to lift if this coil pressure is exceeded. The water formed by the condensation of the steam in each coil passes, through a small hole at the outlet end of the coil, into a pocket. This pocket is drained through a coil drain valve to a condenser, or drain cooler, or direct to the main feed tank. In Weir's evaporators the drain water from the upper coils, and any steam leaving these coils, pass through the lower coil. The amount the coil drain valve is opened should be that found by the makers as sufficient to allow for the passage of the drain water without loss of steam. Feed heaters are now generally fitted, to allow of the heat in the drain water from the coils being transferred to the feed water, and thus returned to the evaporator.

Sea water is supplied to the evaporator by the pump which circulates the cooling water through the distiller. The feed water is taken from the discharge side of the distiller, as this water, being warm, will require less heat to bring it to the boiling point in the evaporator. A spring-loaded valve is fitted on the pipe through which the circulating water passes overboard from the distiller, to maintain a pressure of between 10 and 15 lb. per square inch in the system. An automatic feed regulator maintains the level of water in the evaporator at such a height that the coils are just covered. A gauge glass is fitted, in order that it may be seen whether the regulator is working correctly. The level of the boiling water in the evaporator will be higher than the level in the glass. A window is often fitted on the evaporator shell, to enable the actual level in the evaporator to be seen. An apron plate is fitted in the evaporator around the coils, to cause a circulation of

the water in the evaporator. The feed water enters outside the apron plate, passes down around the bottom of this plate and up through the centre.

If an evaporator primes, that is if the steam leaving the evaporator contains any particles of salt water, pure fresh water will not be produced in the distiller. A baffle is fitted in the upper part of the evaporator, to separate out any water in the vapour. The pressure inside the shell of an evaporator depends on the conditions under which the plant is being worked. At full output with live steam on the coils, the shell pressure will be slightly above atmosphere. With a lower pressure, and therefore lower temperature steam in the coils, a vacuum is maintained in the shell, as the sea water will then boil at a lower temperature. The shell pressure can be varied by opening or closing the valve on the vapour outlet. A safety valve, which lifts at 20 lb. per square inch, is fitted on the shell.

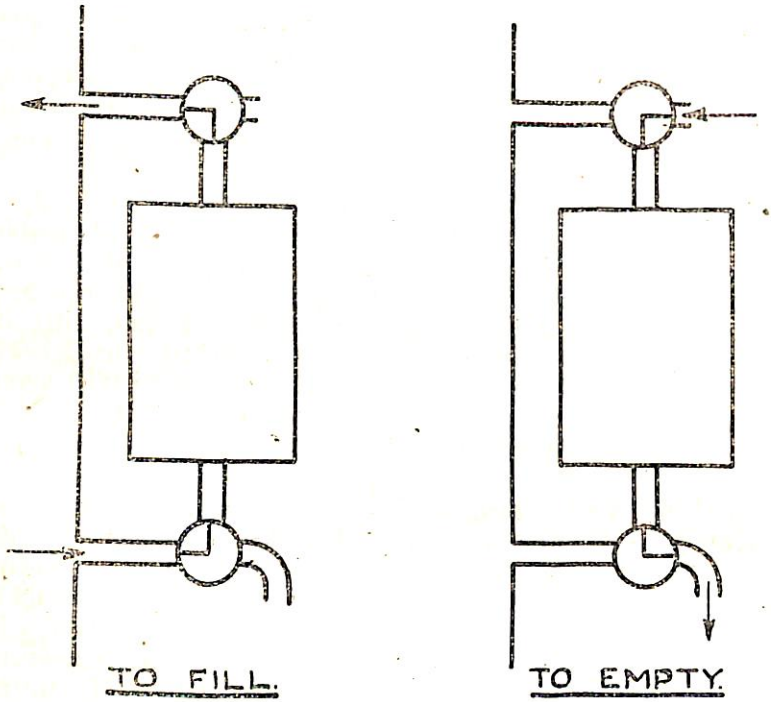
A pump is provided to pump the fresh water from the distiller to the feed tanks or ship's tanks. This pump must be capable of maintaining a vacuum in the distiller. By means of a two-way cock on the discharge from the pump, the water made can be put to the bilge, until it has been ascertained by testing with silver nitrate that it is free from salt. This test must be made periodically, to detect if the evaporator is priming or the distiller leaking. Electrical salinometers are fitted on modern distilling plants, to indicate the degree of purity of the water made.

190. Density of Evaporators.—Sea water contains various salts in solution. The weight of the salts present amounts to about one thirty-second part of the total weight of sea water. When sea water is boiled in an evaporator, water is passing off as steam, but the salts remain. Some of the salts will be deposited in the form of scale on the coils, and this scale will tend to interfere with the transmission of heat from the steam in the coils to the water in the evaporator. As more and more sea water is introduced into the evaporator to replace the water boiled away, the quantity of salts present will increase. The density of the water in the evaporator, which is known as brine, will therefore rise. The rate at which scale forms on the coils increases as the density of the brine rises. To keep the density constant, it is necessary to pump brine from the evaporator at such a rate that the quantity of salts removed in the brine is equal to the quantity of salts entering with the feed. The brine removed is pumped overboard, and a certain quantity of heat is thus lost. The higher the density maintained, the smaller will be the quantity of brine that has to be pumped overboard to keep the density constant. Therefore, the higher the density the lower the heat lost, but the greater the rate that scale

is formed. It is the general practice to maintain a density of 25 degrees in the evaporator. The brine will then contain two and a half times as much salt as is contained in the same weight of sea water. (*See* article 21.)

The density is taken with a brass hydrometer using the scale marked 100° F. Care must be taken that the brine is at this

FIG: 32.



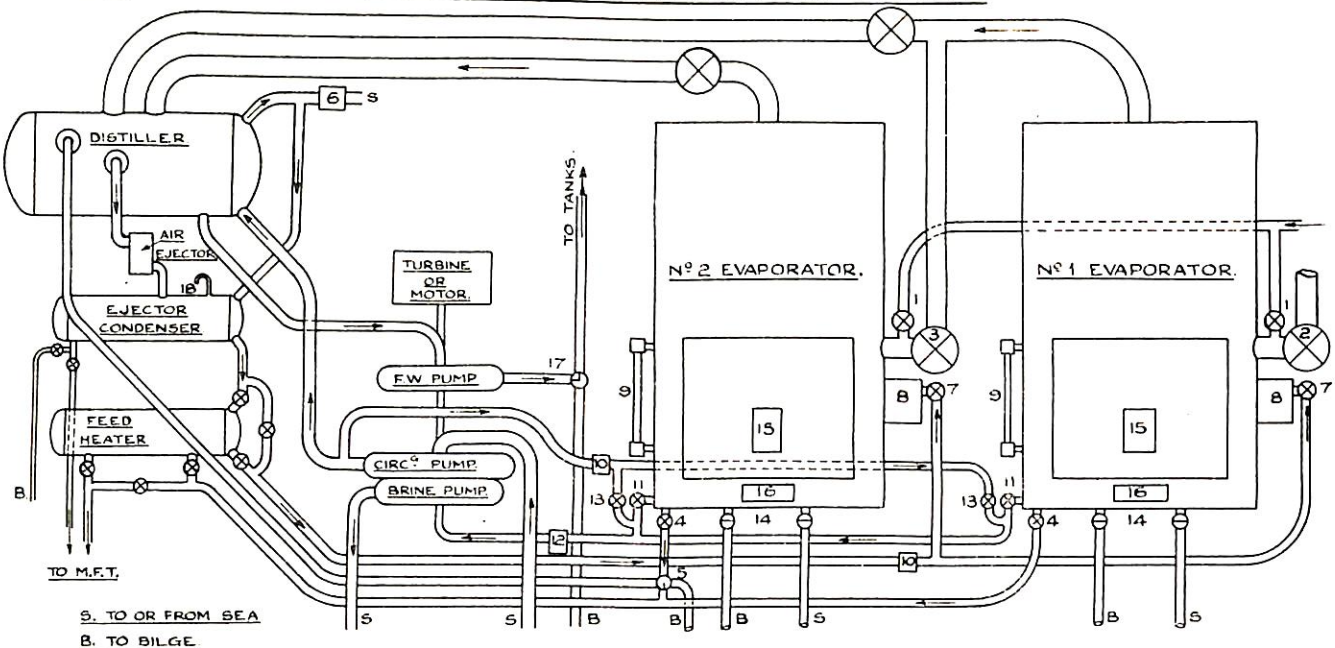
SALINOMETER POT.

temperature, as otherwise the reading will not be the true density. To enable brine to be drawn off for testing when there is a vacuum in the shell, a small vessel known as a salinometer pot is fitted on the lower portion of each evaporator. The top and bottom of this vessel are connected to the evaporator through two-way cocks. By operating these cocks as shown in Fig. 32, the pot can be filled, and then emptied. It should normally be kept empty, and only filled when it is required to take a sample of brine for testing.

A screw-down non-return valve is fitted on the brine suction pipe where it joins the evaporator. As the boiling brine would be

FIG: 33.

COMPOUND EVAPORATOR PLANT.



1. LIVE STREAM TO EVAPORATORS.
2. C.E. " "
3. 1ST EVAPORATOR TO 2ND EVAP: COILS.
4. COIL DRAINS.
5. THREE WAY COCK.
6. SPRING LOADED VALVE.
7. FEED CHECK VALVE.
8. FEED REGULATOR.
9. WATER LEVEL INDICATOR.
10. WEED TRAP.
11. BRINE SUCTION VALVE.
12. SEDIMENT CHAMBER
13. DILUTING WATER VALVE.
14. BLOW-DOWN COCKS.
15. SALINOMETER POT.
16. SEDIMENT DOOR.
17. TWO-WAY COCK.
18. AIR ESCAPE TO ATMOSPHERE.

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difficult to pump, and would deposit salt in the pipes and in the pump, some cold sea water, from the distiller circulating pump discharge, is admitted to the brine suction pipe through a valve known as the diluting valve. The density of the brine in the evaporator can be controlled by adjustment of the brine-suction and diluting valves. The greater the quantity of diluting water admitted to the brine pump, the smaller will be the quantity of brine removed from the evaporator.

191. Single and Compound Effect Evaporators.—A set of evaporators generally consists of two evaporators, one distiller and one combined circulating fresh water and brine pump, but the sets fitted in some small ships only contain one evaporator. Modern destroyers and larger vessels generally have two sets of evaporators, while older destroyers and smaller vessels have one set. Fig. 33 shows a set of evaporators, as fitted in a modern cruiser or battleship. The circulating and diluting water, feed water, coil drain and fresh water pipes can be followed on this drawing. By marking each system of pipes a different colour, the drawing will be made clearer. In addition to the valves shown on this drawing, all pipes which communicate with the sea have a valve on the ship's side or bottom, to allow of pipes, etc., being taken down for repair. These valves should be shut when the set is not in use.

The set of evaporators illustrated can be operated, either as two single effect evaporators, or as a pair working compound effect. When working compound effect, the steam formed by boiling the sea water in one evaporator is used as heating steam in the coils of the other evaporator. Working single effect with live steam to the coils of each evaporator gives the maximum output, but is less economical than working compound effect. It is possible to work the plant shown single effect, with closed exhaust to the coils of No. 1 evaporator, and live steam to the coils of No. 2 evaporator. This method is commonly used when there is a little surplus auxiliary exhaust. Closed exhaust cannot be used in the coils of No. 2 evaporator of this set. The sets fitted in destroyers, and also those in older cruisers and battleships, cannot be worked compound effect, but in those sets closed exhaust steam can be used on both evaporators.

For working compound effect, a pressure of a few pounds must be maintained in the shell of the first evaporator, to provide steam at a sufficiently high temperature for use in the coils of the second evaporator. To obtain a sufficient difference in temperature between the steam in the coils and the brine in the second evaporator, a good vacuum must be maintained in the shell of this evaporator. When working compound effect, the steam condensed in the coils of the second evaporator forms part of the water made by the set,

and the coil drain of the second evaporator should, under these conditions, be led to the distiller. On the coil drain of the second evaporator a three-way cock is fitted, so that the drain water can be put to the feed tank when working single effect, to the distiller when working compound, or to the bilge if the first evaporator should prime when on compound effect. The density of the first evaporator is often kept lower than the density in the second when working compound, as otherwise scale forms more rapidly on the coils of the first evaporator, due to the higher temperature of the coil steam. Either live steam or closed exhaust can be used for compound working. Closed exhaust should only be used when there is more auxiliary exhaust than can be used in the boiler feed heaters. Working compound effect on closed exhaust is the most economical method of distilling, but the output will generally not be sufficient to meet the requirements.

The daily output of a typical set of evaporators, and the quantity of water made per ton of additional oil fuel burnt for distilling, are as follows :—

(*a*) With live steam to both evaporators .. .. 100 tons and 10 tons.
(*b*) With one evaporator on closed exhaust and one on live steam.. 70 tons and 15 tons.
(*c*) Compound effect with 1st evaporator on live steam .. .. 60 tons and 15 tons.
(*d*) Compound effect with 1st evaporator on closed exhaust .. 40 tons and 30 tons.

The outputs with close exhaust are based on the assumption that there is sufficient auxiliary exhaust to maintain pressure of 15 lbs. per square inch in the coils.

192. Distiller.—Sea water is circulated through the tubes of the distiller, and the steam from the evaporators is admitted to the space outside the tubes. The shell of the distiller and the tubes are tinned to prevent contaminating the distilled water. The fresh water suction is so arranged that some distilled water is retained at the bottom of the steam space ; the lower portion of the distiller thus acts as a cooler for the condensate. The sea water admitted to the evaporator as feed contains some air in solution, and this air passes to the distiller with the vapour. In order to maintain a vacuum in the distiller, provision has to be made to withdraw this air.

193. Circulating Fresh Water and Brine Pump.—The pumps, which supply circulating water for the distiller, withdraw the fresh water from the distiller, and brine from the evaporators, are combined in one unit, which is often referred to as the distiller pump or evaporator pump. In some ships a reciprocating pump, with one steam cylinder and three pump barrels, is fitted. In other ships

centrifugal pumps are fitted, the three impellers being driven by the same steam turbine or electric motor.

In the *reciprocating type of pump* the largest barrel directly under the steam cylinder is a double-acting pump, which supplies cooling water for the distiller, diluting water for the brine, and salt water feed for the evaporators. On one side of this sea-water pump is the fresh-water pump, and on the other side the brine pump. These two pumps are single acting, and their plunger rods are connected to a crosshead attached to the top end of the sea water circulating pump rod. In order to maintain a vacuum in the distiller, the fresh-water pump must be large enough to withdraw air in addition to the condensate. Before starting a reciprocating pump, it must be ascertained that all valves on the suction and discharge pipes are open.

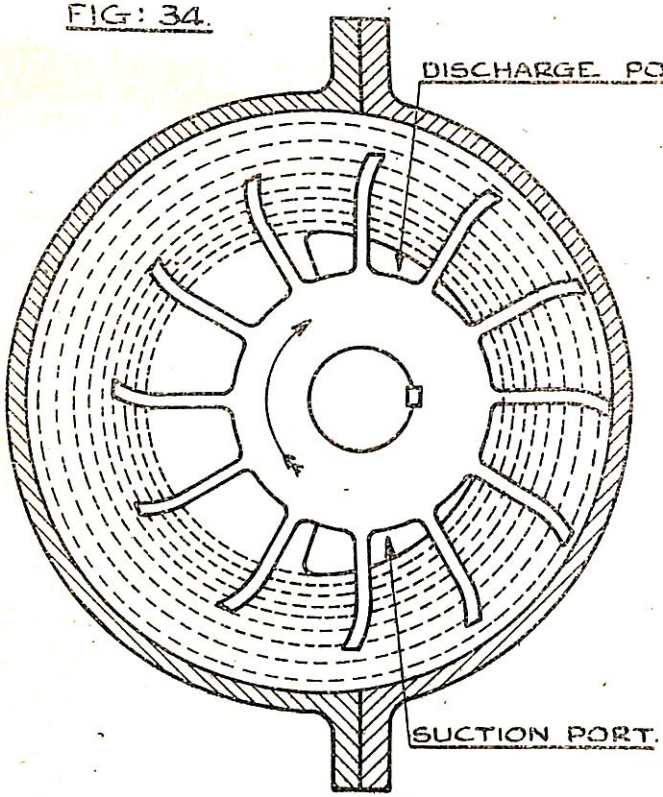
In the *centrifugal type of pump*, the impellers of the circulating and brine pumps are fitted in two chambers in a common casing, the circulating pump impeller being above the brine pump. With this arrangement there is only one spindle gland for the two pumps. The impeller of the fresh-water pump is in a separate casing, fitted above the circulating and brine pumps. Provision is made for venting any air which accumulates on the suction side of these pumps. The circulating pump can be vented to the atmosphere, as the pump is well below sea level. The brine pump is vented to the evaporator, and the fresh-water pump to the distiller. Drain cocks are fitted on each pump chamber. The pump should only be drained when it is not required to be used for some time. Before starting the pump, the suction valves and air vents must be opened, to ensure that the pump chambers are flooded. In the case of centrifugal pumps, the spindle glands are sealed by water under pressure from the discharge side of the pump chamber, and air is less likely to be drawn in through the glands if the discharge valve is kept shut until the pump is running at its normal speed. Grease lubricators are fitted to the bearings on the pump spindle and to the motor bearings of electrically-driven pumps. The roller bearings on the turbine spindle of steam pumps run in an oil bath, as described in article 157. Cooling water is supplied to these bearings from the circulating pump discharge.

A centrifugal fresh-water pump will not withdraw air from the distiller, and some form of air ejector has to be provided to do this. In the set shown in Fig. 33 a single-stage steam jet air ejector is fitted. In this case there is a separate ejector condenser, and the evaporator feed water is used as the cooling medium in order to recover the heat from the steam jet. In some sets the ejector and condenser are incorporated in the same casing, the cooling water is taken from the circulating pump discharge before it goes to the distiller and is discharged overboard. The drain from the

ejector condenser is normally led to a feed tank, but can be put to the bilge in the case of leakage or priming.

Some modern sets have an *Aquair ejector*. This is a rotary pump, which is fitted above the fresh-water pump, and takes its suction from the upper part of the distiller. Air is drawn into the pump and discharged, by the movement of water between the vanes of a rotating impeller. The impeller is fitted eccentrically in a cylindrical casing, as shown in Fig. 34, which is a sectional plan of the ejector looking upwards. The impeller is fixed on the spindle of the distiller pump, above the impeller of the fresh-water pump, and revolves in a separate chamber in an extension of the fresh-water pump casing. This chamber is charged with fresh water. When the pump is running, this water is carried round at high speed by the vanes on the impeller, and takes up the position shown. As the space between two vanes passes the suction port, the water in this space is moving out from the centre, and air is

FIG: 34.



AQUAIR EJECTOR.

drawn in. When this space reaches the discharge port, the water is closing in, and the air is discharged. The pump must be kept charged with the necessary quantity of water. In the casting which forms the pump casing is incorporated a small tank. At the bottom of this tank is fitted a float-controlled drain valve. Before starting the pump, the tank must be filled with fresh water up to the float, and a cock opened to allow water to flood the Aquair chamber. When the pump is running, a little water from the discharge side of the fresh-water pump is allowed to pass to the Aquair chamber, through a small valve locked half a turn open. Surplus water in the Aquair chamber passes out with the air, through the discharge port and into the top of the tank. The water falls into the tank and the air passes to the atmosphere through a non-return flap. Surplus water in the tank passes through the float-controlled valve to the suction side of the fresh-water pump. The cock on the pipe for flooding the Aquair chamber from the tank should be closed when the pump is running and the fresh-water pump discharge valve has been opened. The supply to the Aquair ejector from the discharge side of the fresh-water pump also supplies sealing water for the spindle gland. The cock on this pipe should be kept open while the pump is running.

194. Running Evaporators.—Before leaving the maker's works each set of evaporators undergoes a series of trials. A trial is carried out at the full specified output, with steam at from 20 to 25 lb. per square inch in the coils and a pressure of about half a pound in the shell. A trial is also carried out at a reduced output, with a pressure of 10 to 15 lb. per square inch in the coils and a vacuum of about 20 inches in the shell. If the evaporators are fitted to work compound effect, a trial is also made under this condition. Similar trials are carried out after the plant has been installed in the ship. Records of these trials are provided as a guide for future working, and the settings of the various valves found to give the best results are stamped on a brass plate, which is attached to the evaporator. The maker's trials at reduced output with a vacuum in the shell are made with live steam in the coils. If closed exhaust is used, the coil drain valves will need to be open rather more than on the maker's trials, on account of the greater quantity of moisture in exhaust steam. With clean coils the evaporators should be capable of producing 20 per cent. more than the specified full output. Under constant pressure conditions, the output will fall as the thickness of scale on the coils increases. Some of the scale can be cracked off the coils by emptying the evaporators to the sea through the blow-down cock and refilling with cold sea water. This is known as blowing down, and is generally done every twelve hours. (*See* article 195.) It

is rarely necessary on board to work the evaporators at their full output. The general practice is to use a low coil pressure when the coils are clean, and to increase this pressure as necessary to maintain the required output. After a week or more in use, the output will probably have fallen so much that it will be necessary to clean the coils.

The principal difficulty met with in running a set of evaporators is priming. This is particularly liable to occur when a large volume of steam is being liberated from the surface of the brine in the evaporators. The volume of steam liberated will depend on the output, and also on the pressure in the shell. For the same output, the lower the shell pressure the greater is the volume of the steam formed. From a point of view of transfer of heat from the coils to the brine, it is advantageous to boil the brine under a vacuum, as its temperature will be lower. While this can be done at reduced outputs, if attempted at full output priming would result. Unsteady conditions will tend to cause priming; the water level, the density, and the coil and shell pressures should be kept as steady as possible. There is no advantage in maintaining a high vacuum in the distiller, when running evaporators single effect with a slight pressure in the shell. In sets with jet air ejectors, the vacuum in the distiller can be controlled by adjusting the steam pressure in the ejector nozzle box.

Evaporators should be started up with the vapour valves closed, and these should be opened gradually when there is a slight pressure in the shell. The discharge from the fresh-water pump, and also the coil drain from the first evaporator if on compound effect, should be put to the bilge, until it has been ascertained that the water made is free from salt. If it is not possible to produce pure water, the fault may be either priming or a leak in the distiller. A small coil is normally supplied, which can be connected to the vapour outlet, and some water collected which has not passed through the distiller. If this water is free from salt, the fault must be in the distiller, and the set must be shut down until the defect has been made good. In a set such as that shown in Fig. 33, it is possible for the water in the feed tanks to be contaminated by a leak in the ejector condenser or feed heater. The drain water from these should also be tested on starting, and periodically when the set is in use. When shutting down evaporators, the vapour valves should be closed before shutting steam off the coils.

195. Blowing Down and Cleaning Evaporators.—To blow down evaporators to the sea, it is necessary first to raise a pressure of 20 lb. per square inch in the shell. This is done by closing the vapour valves, and putting a pressure of 25 lb. of live steam on the coils. Steam should be shut off the ejector, if fitted, and the

evaporator pump stopped. If the coil drain of the second evaporator is on the distiller, it should be changed over to the feed tank temporarily.

When the desired shell pressure has been obtained, open the blow down to the sea. By watching the water level in the gauge glass, it can be judged when the evaporator is empty, the coil steam should then be shut off. Leaving the blow-down cock open, start the pump to spray cold water into the evaporator through the feed check. A vacuum will be created by the condensation of the steam in the shell, and sea water will rush in through the blow-down cock. Again by watching the level in the gauge glass, it may be judged when the top coil is covered. The sudden contraction of the hot coils, caused by the influx of cold sea water, will cause the scale to crack and some of it will fall off. The operation may be repeated, to blow out some of the scale which has fallen from the coils, and to crack off a further quantity. The water level must be restored to the correct working height before bringing the set into production, either by raising sufficient pressure in the shell to blow the surplus water overboard, or by draining it to the bilge. An undue accumulation of scale at the bottom of the evaporator will choke the passage round the bottom of the apron plate, and thus interfere with the circulation of the brine. The set should be shut down occasionally, and the loose scale removed through the sediment door.

The period for which an evaporator can be kept in use, before it becomes necessary to remove the coils for cleaning, depends on the success of the operation just described, and this depends on the condition of the coils. When it is necessary to clean the coils, they are removed through the large door on the front of the evaporator. In some ships, the scale is removed by heating the coils over a forge, but hammering the coils is the normal method employed. To prevent distortion of the coils, or denting of the surface, only light copper hammers should be used. By keeping the coils in a good condition with a smooth surface, cracking off of scale by blowing down the evaporator is greatly facilitated. The coils are sometimes given a coat of blacklead or graphite before being replaced in the evaporator, to facilitate the subsequent removal of scale. When all the coils have been replaced and before closing the door, a steam pressure of 25 lb. per square inch is put on the coils, to ascertain whether all the connections are steam tight. A leakage of steam from a faulty coil connection may cause an evaporator to prime. Also when the evaporator is shut down and the steam in the coils condenses, brine may be drawn into the coils, and contaminate the feed water next time the evaporator is used. Some evaporators have a cock fitted above the coil drain valve, so that

before opening this valve a test tube of water can be drawn off and tested.

196. Steering Gear.—In all except very small vessels, it is necessary to provide some form of power to operate the rudder. Power-operated steering gear may be either one of two types :—

(1) *Electro-hydraulic steering gear*, in which the tiller, secured to the inboard end of the rudder post, is moved by two or four hydraulic rams, oil being supplied to operate these rams by electrically-driven pumps.

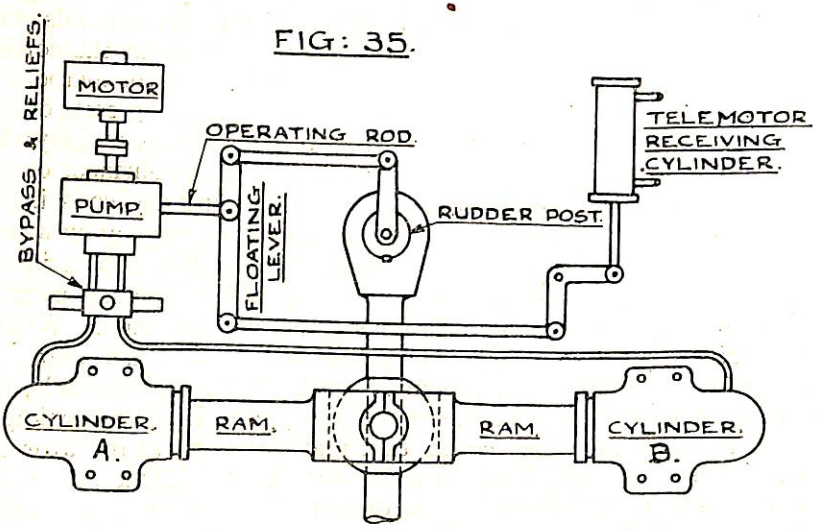
(2) *Steam steering gear*, in which the tiller is operated by a steam engine through suitable mechanical gearing.

Nearly all modern ships have the electro-hydraulic gear. Steam steering gear will be found in the older ships and in some of the smaller vessels built recently.

In all larger ships, the source of power is duplicated, two pumps being provided with electro-hydraulic gear and two engines with steam steering gear. Also, in order that a ship may be steered if the normal source of power should not be available, provision is made so that the rudder can be operated slowly by hand. In some ships with electric-hydraulic steering gear a steam pump is provided for use if current is not available for the electric pumps This is known as the emergency or auxiliary steering arrangement.

197. Electro-hydraulic Steering Gear.—Fig. 35 shows diagrammatically the arrangement of the electro-hydraulic steering gear in a small ship. The two cylinders A and B, the pump, and the

FIG: 35.



HYDRAULIC STEERING GEAR.

connecting pipes are charged with special mineral oil. The pump, which is driven at constant speed by an electric motor, can pump oil from the ram cylinder A to the ram cylinder B, or vice versa, and so move the tiller in either direction. There are two types of pump fitted—the Hele-Shaw and the Williams-Janney. The stroke of these pumps can be varied while they are running, and also the flow of oil into and from the pump can be reversed. With the operating rod in the mid position, no oil is drawn into the pump or discharged. By moving the operating rod in one direction, oil will be discharged from cylinder A to cylinder B, while by moving the rod in the other direction oil will be discharged from B to A. To replace any oil lost from the system, a replenishing tank is provided with a connection through a non-return valve to each side of the pump. This tank must be kept charged with special mineral oil. Spring loaded relief valves prevent an excessive pressure in the system.

To ensure that the angle through which the rudder moves shall correspond with the movements of the steering wheel, what is known as hunting gear is fitted. Movement of the steering wheel is transmitted through a telemotor system to one end of a floating lever, to which the operating rod of the pump is attached. The other end of this floating lever is connected to an arm on the rudder post. If the steering wheel is moved, say half a turn, the pump will commence to transfer oil from one cylinder to the other, and the rudder will be moved. Movement of the rudder tends to return the operating rod to the mid position, and when the rudder has moved through an angle corresponding to half a turn of the steering wheel, the operating rod will be back in its mid position, and the pump will cease to transfer oil.

Two pumps are generally fitted, and change over switches are provided so that the current from each motor can be taken from either side of the ring main (*see* Article 202). One pump is sufficient to move the rudder at the specified speed, but both pumps are always used as a precautionary measure when entering and leaving harbour. It may also be desirable to use both pumps when manœuvring with other ships in company. In destroyers, provision is made so that the stroke of the pumps can be restricted, in order that the speed at which the rudder is put over shall not be increased when both pumps are running. If when both pumps are in use, one should stop, due to an electrical failure, it is necessary to prevent the pump with the dead motor being driven in the reverse direction by the running pump. In small ships each pump is fitted with a pawl, which prevents it being reversed; while in the larger ships solenoid controlled valves, which close if there is no current flowing to the motor, are fitted on the pipes from each pump. The starters for the pumps are fitted in the engine room in small ships, and in the steering gear

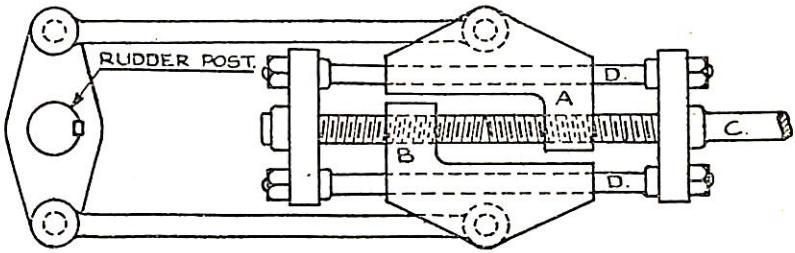
compartment in the larger ships. Indicator lamps are fitted at the pumps, and also in the control engine room, to show which pumps are running. There is also an alarm buzzer circuit, to warn the helmsman and the watchkeepers in the engine room if the pump should stop. When stopping one pump after leaving harbour, the alarm circuit for this pump can be broken by pressing a button on the starter. Should both pumps fail while the rudder is over, it is desirable that the rudder should be brought to the midship position quickly. This can be done by opening a by-pass valve connecting the pipes to the two cylinders.

In cruisers and larger ships, a double-ended tiller is fitted, with two rams and cylinders for each arm.

The *emergency steering arrangement* in battleships consists of an additional pump in the engine room, similar to the electric pumps, but driven by a steam turbine instead of an electric motor. One end of the floating lever of this pump is mechanically coupled to a steering wheel fitted close to the pump, while the other end is operated from the tiller through a telemotor system. In cruisers and smaller ships, a hand pump and change-over valve are provided in the steering gear compartment.

198. Steam Steering Gear.—In ships with steam steering engines, the type of steering gear usually fitted is that shown in Fig. 36. The nut A engages with a right-handed screw thread on the shaft C, while nut B engages with a left-handed thread. These nuts are prevented from rotating by the guide bars D. Rotation of the screwed shaft in one direction will cause A and B to separate and the rudder will be moved to turn the ship to port, while rotation of the shaft in the other direction will turn the ship to starboard. The shaft C is driven by a small reversible reciprocating steam engine. A two-cylinder engine is employed, with the cranks at 90 degrees with one another, and the supply of steam to the engine is controlled by a differential valve, as described in Article 126. The differential valve is operated from the steering wheel, either by means of control shafting, or through a telemotor system. Hunting gear is fitted, to bring the engine to rest when the rudder has been moved through an angle corresponding to the amount of helm put on at the steering wheel. This hunting gear consists of a worm on the crankshaft of the engine, driving a worm-wheel which moves the differential valve in the opposite direction to that in which it has been moved by the rotation of the steering wheel. The differential valve can be operated at the engine by disconnecting it from the control shafting or telemotor system, and a clutch is provided for disconnecting the engine from the steering gear. This allows of the engine being warmed through before proceeding to try the steering gear, as described in Article 200.

FIG: 36.



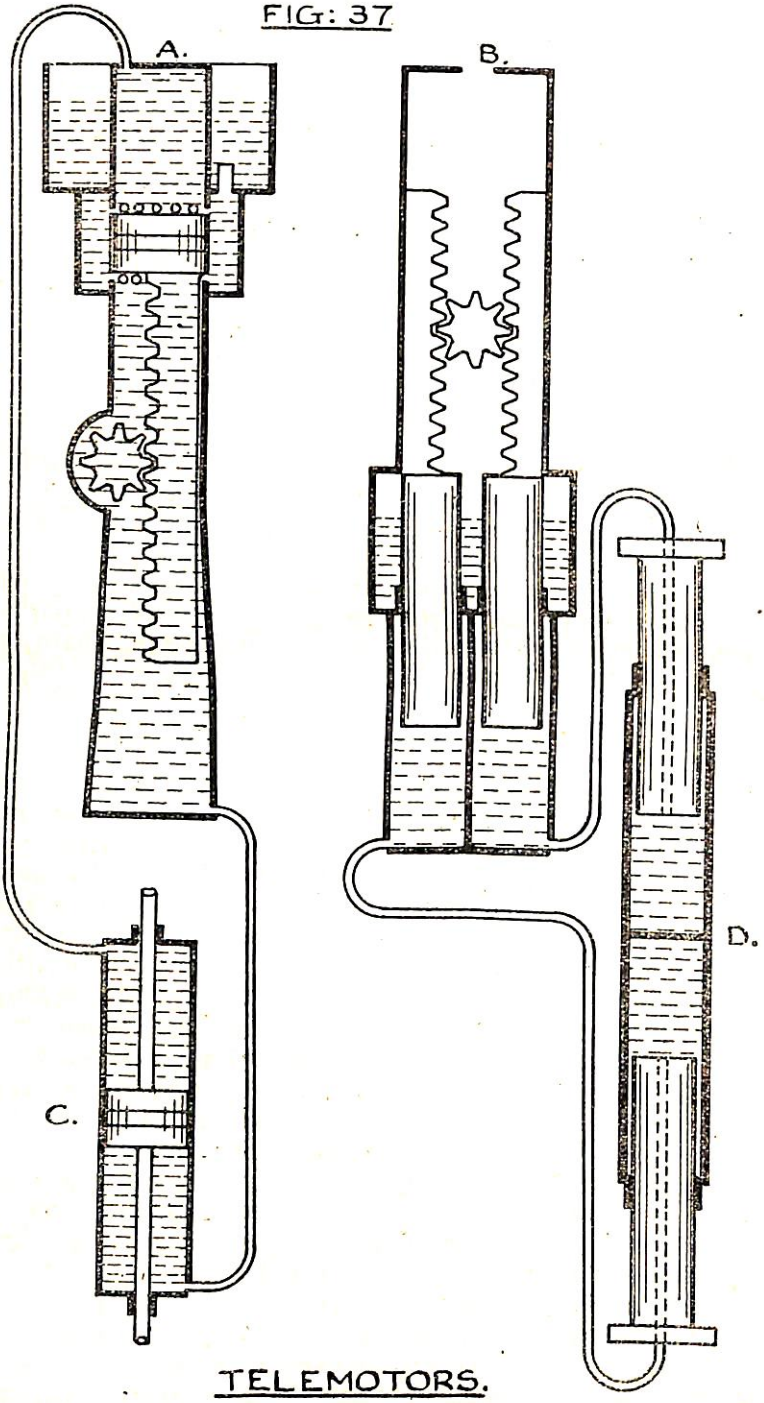
SCREW STEERING GEAR.

In small ships, a single steering engine is fitted, either in the engine room or in the steering gear compartment. In larger ships, there are two steering engines in the engine room, either of which may be coupled up to the steering gear.

The *emergency steering gear* consists of one or more large wheels on a shaft in the steering gear compartment. By coupling this handwheel shaft to the steering gear, instead of the shaft driven by the engine, the rudder can be operated by hand.

199. Telemotor System.—In nearly all ships, the movement of the steering wheel is transmitted to the differential valve of the steam steering engine, or to the control rod of the pumps of electro-hydraulic gear, through a telemotor system. A telemotor consists of two cylinders connected by pipes and charged with fluid, so that movement of the piston in one cylinder, called the transmitter, causes a corresponding movement of the piston in the other cylinder, called the receiver. The transmitter is actuated by the steering wheel, by means of a rack and pinion. It may consist either of a single cylinder with fluid on both sides of the piston, as shown at A in Fig. 37, or of two cylinders with rams which move together, but in opposite directions, as at B. Similarly, the receiver may consist of a fixed cylinder and a piston free to move, as shown at C, or of two fixed rams and a double cylinder free to move on these rams, as at D. Movement of the piston or cylinder at the receiver end actuates the differential valve or pump control rod. A large spring is fitted at the receiver, which is compressed by movement of the piston or cylinder from the mid position in either direction. This spring is strong enough to return the receiver and the transmitter to the mid position, when the steering wheel is released. Two pressure gauges are fitted at the transmitter, one to each side of the system. If the receiver follows the transmitter when helm is put on, then one or other of these gauges will register the pressure

FIG: 37



TELEMOTORS.

necessary in the system to compress the receiver spring. The helmsman is able to see by watching these gauges that the telemotor is functioning correctly.

To prevent the transmitter and receiver getting out of step with one another, if there should be a slight leakage past the pistons, at the transmitter end a by-pass is provided, which connects the two sides of the telemotor system when the transmitter is in the mid position. There is also at the transmitter end a replenishing tank, to which both sides of the system are connected when the wheel is amidship. This allows for any change in the volume of liquid in the system due to change of temperature.

The pipes connecting the transmitter and receiver are duplicated, one pair of pipes being led down each side of the ship. It is also general practice to fit two receivers, to provide against possible failure of the packing rings. There is generally more than one steering position, and change-over valves are provided to allow of the transmitter at either steering position being connected to either receiver through either lead of pipes. In order to avoid the necessity of a large number of change-over valves, double transmitters have been introduced, each transmitter operating its own receiver through a separate lead of pipes. The steering wheel, therefore, operates the control rod of the pump through two entirely separate telemotor systems. Provision is made so that in the event of failure of one of these systems, the transmitter and receiver of this system can be disconnected, and repairs carried out while the other is in use. In the event of a complete failure of the telemotors, the steering engine or pump can be operated locally. This is known as mechanical control.

The fluid used in steering telemotor systems is generally a mixture of 30 parts glycerine to 70 parts distilled water. In very cold climates a 50 : 50 mixture should be used. In some of the older ships the telemotor system is charged with oil. A charging tank is fitted at the receiver end, and a hand pump for pumping the fluid into and around the system. Plugs are fitted at various points on the system for the release of air when charging. If there is any air in the system the telemotor will not function correctly. The handbook supplied by the makers of the gear should be consulted as to the procedure to be adopted when charging or testing for air in the system. After charging, and once every week, a creep test is applied to each telemotor system. With the steering wheel lashed hard over, there should be no creeping back of the receiver. This test must be applied to each side of the system.

200. Preparation of Steering Gear.—When preparing the steering gear for use, a thorough examination must be made to ensure that there is nothing which can obstruct the gear, or the control

shafting if fitted, and all the lubricating arrangements must be attended to. In the case of steam steering gear, the engine should be warmed through, and run a few revolutions in each direction with the steering wheel and the steering gear disconnected. The engine should then be coupled to the gear, and the rudder put hard over each way by operating the differential valve locally, the indicators at the rudder post and on the engine being watched to see that they register the same amount of helm. In the case of electro-hydraulic gear, after starting one of the pumps, the gear is first tested by operating it from the mechanical control position in the steering compartment.

When it has been ascertained that the gear works satisfactorily from the local position, the steering wheel is connected, and the rudder is again put hard over each way, the indicators at the wheel and at the rudder post being checked.

201. Capstans and Windlasses.—In large vessels capstans are fitted for raising the chain cables and for hauling wire ropes when bringing the ship alongside a jetty, while small vessels have a windlass for this purpose. When the drum around which the cable or rope is passed revolves about a vertical axis, it is called a capstan ; while if the axis of rotation is horizontal it is called a windlass. When the drum of a capstan is so shaped that it is suitable only for use with chain cable, it is called a cable holder.

In large vessels, two cable holders are fitted on the forecastle deck, one on each side, and a capstan on the centre line forward of the cable holders. Each is mounted on the top of a vertical spindle extending to a bearing fitted on a deck below the forecastle deck. This bearing, which is known as a footstep bearing, takes the weight of the spindle and capstan. To the lower end of each spindle is attached a large worm wheel, which meshes with a worm on one of three horizontal shafts. The worm shaft of the centre line capstan lies fore and aft, and is driven by a steam engine or electric motor. The two worm shafts for the cable holders are in line with one another, and lie athwartship. They are driven from the fore and aft shaft through bevel gearing and clutches, which are so arranged that each cable holder can be caused to rotate in the same direction as the centre line capstan or in the opposite direction. The spindle of the centre line capstan can be freed from its worm wheel, and a number of sockets are provided in the capstan, into which capstan bars can be inserted for revolving the capstan by hand. In each cable holder is a clutch, whereby it may be connected to, or disconnected from, its spindle, and a brake is fitted to control the drum when the clutch is in the free position. In some large ships, there is also a capstan fitted at the after end. This capstan is invariably electrically driven.

In modern ships, except destroyers and smaller craft, the forward capstan and cable holders are driven by an electric motor. In the older destroyers and larger vessels, a vertical steam reciprocating capstan engine is fitted between decks, while modern destroyers have a horizontal steam capstan engine on the forecastle deck.

Steam capstan and windlass engines are two-cylinder reversible engines, with the two cranks at 90 degrees to ensure starting from any position in which the engine may stop. The engine is controlled by a differential valve, as described in Article 126. Particular care must be taken, when the engine is fitted on the forecastle deck, that the cylinders, slide chest, steam and exhaust pipes are kept thoroughly drained in cold weather, to prevent damage by freezing when the engine is not in use.

CHAPTER XIV.

ELECTRIC GENERATORS, REFRIGERATING MACHINERY, HYDRAULIC PUMPS AND AIR COMPRESSORS.

202. Electric Generators—General.—An electric generator consists of a dynamo, and an engine to drive the dynamo. A small portion of the work done by the engine is lost as heat, the remainder is converted by the dynamo into electrical energy. This electrical energy can be conducted through cables to any desired position, and then converted into light or heat, or used to drive an electric motor.

In ships either steam or internal combustion engines are used to drive the dynamos. The most convenient form of steam engine is the turbine, and internal combustion engines used are almost invariably of the diesel type. The electric generators of ships are therefore either turbine driven or diesel driven, and are known as turbo generators and diesel generators.

By rotating the armature of a dynamo in the magnetic field set up by the poles, a difference in potential is produced between the two terminals of the armature circuit. If these two terminals are connected through an external circuit, an electric current will flow through this circuit, and through the armature. The difference in potential across the terminals of a dynamo is measured in volts, and the strength of the current flowing in the circuit in amperes. The product of these is a measure of the quantity of electrical energy produced. For example, if the difference in potential across the terminals is 100 volts, and a current of 200 amperes is flowing through the circuit, the output is 20,000 watts or 20 kilowatts. A dynamo is designed for a certain selected voltage and maximum output. The voltage adopted for practically all H.M. ships is 220, but a few small ships have 100-volt installations.

It is important that the voltage be correct, a reduction of only a few volts will cause all the lights to be dim, while a slight increase above the designed voltage will shorten the life of the electric lamps. The voltage of a dynamo depends on (*a*) the speed of rotation of the armature, and (*b*) the strength of the magnetic field between the poles.

The engine used to rotate the armature is fitted with a *speed governor*, which should maintain the speed practically constant under varying loads. The governor can be adjusted, and a tachometer is fitted in order that the dynamo watchkeeper may see that the engine is running at the correct speed. When once the

governor has been correctly set, it should not normally be necessary for any further adjustment to be made.

If the dynamo is running at the correct speed, the switchboard watchkeeper can alter the voltage as necessary, by increasing or decreasing the magnetic field between the poles by means of what is known as a *shunt regulator*. In small ships the shunt regulator is fitted on the main switchboard, while in cruisers and larger ships the regulator is fitted close to the dynamo and is normally operated by a small reversible motor controlled from the switchboard.

An instrument, known as a *voltmeter*, which shows the voltage across the terminals of the dynamo, is fitted in the dynamo room and at the switchboard. An electric lamp, known as a pilot lamp, is fitted in a circuit across the dynamo terminals to indicate that the dynamo is running.

Another instrument, known as an *ammeter*, shows the current flowing in amperes ; this is referred to as the load. A red mark on the ammeter indicates the maximum load for which the dynamo is designed. The ammeter will register zero until the dynamo has been connected to the ship's mains. This is done by a large electrically-operated switch known as a *supply breaker*, which is situated in the dynamo room. The supply breaker is normally operated electrically from the switchboard, but by changing over a link in the local control unit fitted adjacent to the breaker it can be operated from the dynamo room. The supply breaker is disconnected automatically if the load put on the dynamo exceeds a predetermined amount, usually 75 per cent. above the normal full load. A reversal of the current in a dynamo will also disconnect the supply breaker. This prevents a dynamo receiving current from another generator and running as a motor, if the supply of steam or fuel to the engine be shut off, either accidentally or by the overspeed governor. A considerable amount of damage might be done to the engine if a dynamo were allowed to motor. As an additional precaution the overspeed governors of modern electric generators are fitted with a switch which opens the supply breaker if the governor trips.

In all except the smallest ships a number of electric generators are fitted, and to prevent them all being put out of action by damage to one part of the ship, some are fitted forward and some aft. Destroyers have two turbo generators, and one or two small diesel generators which are mainly for use in harbour. Cruisers have four electric generators, usually of equal output, two of which may be diesel driven. Battleships have up to eight electric generators.

The electric generators of cruisers and larger ships supply current to what is known as a *ring main*. This consists of a pair of cables fitted along each side of the ship, and joined at the forward and after ends by cables running across the ship. Connected at intervals

along the fore and aft portions of the ring main are groups of *branch breakers*, through which current can be supplied to the various lighting circuits and electric motors. *Ring main breakers* are fitted, to enable the ring main to be divided into as many sections as there are electric generators. The ring main breakers and the branch breakers are normally operated electrically from the switchboard, but they can be changed over to local control. With all the ring main breakers made, any generator can supply the whole of the ship, or if the load is too great for one generator two or more may be used and the load divided proportionately between them. Two or more generators supplying current to an undivided ring main, or to the same section of a ring main, are said to be *running in parallel.* It is uneconomical to run more electric generators than are necessary, and in harbour one or two generators supplying an undivided ring main will generally meet the requirements. If one of two generators running in parallel should stop, all the load will be thrown on the other. If the total load in these circumstances is more than one generator can carry, immediate steps must be taken by the switchboard waterkeeper to reduce it, by switching off branch breakers supplying unimportant services. If the load on the running generator should be greater than that at which the supply breaker has been set, the breaker will be disconnected by its *overload release.* There will then be a complete failure in the supply of electricity, all the electric lights will go out and all the motors stop. Certain essential services, such as steering motors, navigation lights, gun circuits, etc., can be supplied from either side of the ring main. By splitting the ring main into two, and supplying each half from one or more electric generators, failure of these essential services can be guarded against. In action all electric generators are kept running and all ring main breakers disconnected. Damage to a section of the ring main will then only affect the part of the ship supplied from that section. Should the compartment containing an electric generator be flooded, the short circuiting of a *flood switch* in the compartment will cause this generator to be disconnected from the ring main by disconnecting the *dynamo fuse release switch.*

Destroyers and other small ships are not fitted with a ring main with branches to various circuits. All circuits in these ships are lead to a switchboard, the forward circuits to a switchboard forward, and the after circuits to a switchboard aft. At sea the after steam-driven electric generators supply current to the after switchboard direct, and also through interconnecting cables to the forward switchboard. Similarly in harbour the forward oil-driven generators supply the forward switchboard direct, but can also supply the after switchboard. Any generator can therefore feed any circuit.

The types of turbo generator fitted in H.M. ships are described in the following article and diesel generators in Chapter XV.

203. Turbo Generators. The tubines of all turbo generators now fitted in H.M. ships are of the impulse type, and drive the dynamo through gearing. For generators up to 150 kilowatts, as fitted in destroyers and other small vessels, the turbines have a single impulse wheel with two rows of blades. The exhaust steam from these turbines is lead to the auxiliary exhaust range, and is generally used for feed heating or distilling.

The turbo generator sets fitted in larger ships are self-contained, each set having its own condenser, circulating pump, extraction pump and air ejector. The steam being expanded in the turbine down to condenser pressure, the turbines of these sets usually have about six pressure stages, the first wheel having two rows of blades and the remainder one. The condenser is situated below the turbine at the exhaust end. The circulating and extraction pumps are generally driven from the turbine spindle through spiral bevel gears, but in few of the older ships a small auxiliary turbine is provided to drive these pumps. A two-stage jet air ejector withdraws air from the condenser. Some of the air ejectors fitted are cooled by sea water, but in all modern sets the extraction pump discharge passes through the ejector cooler on its passage to the feed tank. To ensure an ample supply of cooling water to a condensate cooled ejector when the generator is running light, a by-pass valve is fitted, which allows of the extraction pump discharge being returned to the condenser.

There are in some cases three valves on the steam supply to the turbine: (1) a hand-operated stop valve; (2) an emergency overspeed valve; and (3) a double-seated valve controlled by the speed governor. Some firms fit only two valves, by arranging that the emergency governor shall operate the stop valve.

When a generator is in use the stop and emergency valve or valves should be wide open. The supply of steam to the turbine will then be controlled by the governor valve, which is operated by the speed governor through an oil relay. On an extension of the spindle of the speed governor valve is a piston, which works in a small cylinder known as the relay cylinder. A spring on one side of the relay piston tends to keep the valve closed, while oil under pressure is admitted to the other side of the piston. A small piston-type pilot valve, operated by the speed governor, controls the supply of oil to the relay cylinder. When the load on the dynamo is increased the speed of the turbine starts to drop. The centrifugal force on the weights of the speed governor is reduced, and the weights move until the tension of the spring balances the lower centrifugal force. The movement of the weights is communicated to the pilot valve, thus increasing the opening of the port

through which oil is supplied to the relay cylinder. The rise in pressure in the relay cylinder thus produced opens the steam valve a little further, admitting to the turbine the increased quantity of steam necessary for the larger load. Similarly an increase in speed due to a reduction in load, is checked. It is evident that the position of the pilot valve, and therefore of the governor weights, will depend on the amount it is necessary for the valve controlling the supply of steam to be open, to meet the load on the dynamo. The total movement of the pilot valve is however very small, and the difference in speed when running at full load and when running light amounts to only about 5 per cent. Provision is made to allow for alteration of the speed maintained by the governor, by altering the axial position of the sleeve in which the pilot valve works. Once the governor has been set it should not be necessary to alter the adjustment. The switchboard watchkeeper is able to bring about any slight change in voltage required, by means of the shunt regulator. When a generator is running, oil at a pressure of about 60 lb. per square inch is supplied to the relay system, by a pump driven by a worm and worm wheel from the turbine spindle. Should this pump fail to maintain a pressure, the governor valve will close, and the generator will stop. For starting, provision is made, either to lift the governor valve by means of a lever, or to pump up a sufficient oil pressure by means of a hand pump.

To achieve maximum economy when running on light loads, some of the nozzles must be shut off, to maintain a high steam pressure in the nozzle box. Some firms fit two double-seated steam valves, each controlling the steam to a different set of nozzles, both these valves being controlled by the same governor. Up to about half power one valve will pass all the steam required. Further movement of the pilot valve, after the first steam control valve is wide open, brings the second steam control valve into operation. In a few turbo generators a hand-operated valve has to be opened, when the load on the dynamo is more than half the designed full load. Opening this valve allows the steam passing the governor valve to pass to additional nozzles. It will usually be found that when only one governor valve is fitted, this valve controls the steam to a sufficient number of nozzles for the generator to develop the designed maximum load, provided there is no undue drop in boiler pressure, and there is a good vacuum in the condenser. In order that the full designed output may still be obtained should the boiler pressure fall, or the vacuum in the condenser be reduced, all turbo generators are fitted with a few extra nozzles controlled by a hand-operated valve known as an overload valve. When a turbo generator is running at near its full load a watch must be kept on the pressure in the nozzle box. If this pressure approaches the pressure on the boiler side of the governor valve, the maximum

power which the turbine can develop on the nozzles which are open will have been almost reached. A further increase in the load on the dynamo may bring about a reduction in speed, unless the overload valve is opened. All turbo generators are designed to produce an overload of 10 per cent. above the normal output for two hours, and those fitted in the latest ships can take an overload of 50 per cent. for 15 minutes.

A supply of oil for lubricating the turbine bearings and gearing is sometimes taken through a reducing valve from the discharge side of the oil pump supplying the governor relay system, but some makers fit a separate low-pressure oil pump to supply the forced-lubrication system. The pumps take their suction from a well or tank, into which the oil leaving the bearings, gear case and relay cylinder drains. Strainers are fitted, either on the suction side, or on the discharge side of the oil pumps. The lubricating oil for the bearings and gearing passes through an oil cooler, the cooling water being provided by the circulating pump in self-contained sets, and in other cases by the main circulator or water service pump. As the bearings might be damaged when starting before a supply of oil from the mechanically-driven oil pump reaches them, a hand pump is provided. In some turbo generators the same pump can be used to pump up a sufficient pressure in the oil relay system to lift the speed governor valve off its seat. When the same mechanically-driven oil pump supplies the forced-lubrication system and the oil relay, should this pump fail to maintain a pressure the governor valve will close and shut off the steam. When two pumps are fitted, it is arranged that a failure of the forced-lubrication pressure allows a spring to close a valve, which cuts off the oil supply to the relay cylinder.

Certain bearings are not supplied with oil from the forced-lubrication system. The armature end bearing remote from the turbine is either a grease lubricated roller bearing, or a plain bearing with ring lubrication. The bearings on the circulating and extraction pump spindle of self-contained sets are fitted with grease lubricators. Other parts that require the application of a small quantity of lubricant occasionally are the tachometer, governor gear links, and sliding feet at the steam inlet end of the turbine.

To prevent damage to the condenser, due to an excessive rise of pressure if the circulating pump should fail, some self-contained turbo generator sets are fitted with a safety arrangement to shut steam off the turbine should the vacuum fall below 10 inches.

On account of the differences in the turbo generators of different makers, it is not possible to give detailed instructions for starting and running. All the firms issue handbooks, and the instructions contained in these should be followed. Uniform heating of the turbine can best be ensured, by allowing the turbine to revolve

slowly as soon as steam is admitted. Warming a turbine by the admission of steam with the rotor at rest will cause distortion of the rotor due to local heating, and damage may result when the rotor starts to revolve. Care must be taken that the steam pipe is thoroughly drained before opening the steam valve, and all drains on the turbine must be kept open during the warming period. The supply of oil to the bearings with the hand pump must be kept up, until the turbine is running fast enought for the mechanical pump to maintain the necessary pressure. When test cocks are fitted at the bearings, these should be tried to ensure that oil is reaching all the bearings. In self-contained sets, after packing the turbine glands, a vacuum of 15 or 20 inches is raised in the condenser, to ensure that the rotor shall revolve as soon as the throttle valve is cracked. The second stage only of the air ejector should be used for this purpose. There will be no circulation of cooling water through the condenser or ejector cooler until the turbine is revolving. In the case of condensate cooled ejectors, circulation may not start until the extraction pump is running at near its full speed. Steam should not be opened to the first stage of the air ejector until the generator has been run up to its working speed.

On starting a turbo generator should be run at slow speed for about five minutes, the steam supply being throttled at the stop valve. It should then be worked gradually up to the running speed, the tachometer, being watched carefully as this speed is approached, to see that the speed governor is functioning correctly. The oil pressure gauges on the relay and forced lubrication systems should now register the normal pressure. If either of these pressures should be unduly low, the generator should be stopped and the reason ascertained. The hand release of the emergency governor should now be operated, to ensure that the valve is free and capable of stopping the turbine. To reset the emergency trip, the stop valve must be closed, and where the emergency valve is separate from the stop valve, the steam on top of the emergency valve must be released through a drain before the valve can be opened. The generator may now be restarted, and as soon as it is running at the correct speed with the stop valve wide open, the switchboard watchkeeper should be informed that the generator is ready.

204. Refrigerating Machinery.—Refrigerating machines are fitted in warships, to cool refrigerating chambers for the storage of meat and vegetables, to make ice, and also in the larger vessels, to cool the magazines. Small refrigerators are also fitted in the living spaces, to provide suitable stowage for ready use stocks of butter and other perishable foods in hot weather; these are known as domestic refrigerators.

All refrigerating machines fitted in H.M. Ships are of the com-

pression type. The principle on which they work is that certain gases can be liquified at atmospheric or sea temperature if compressed to a sufficiently high pressure, and the evaporation of this liquid under reduced pressure results in a very appreciable drop in temperature. The gases used are known as refrigerants. In modern refrigerating machines the liquid refrigerant is evaporated in cooling coils in the refrigerating chamber, this is known as direct expansion. In the machines fitted in the older ships, the cold refrigerant is used to cool brine, which is then circulated through the cooling coils.

Latent heat and boiling point.—Heat must be supplied to a liquid to convert it into a gas, and to reconvert the gas into a liquid heat must be given up. This heat is called the latent heat of evaporation. If a volatile liquid, such as methylated spirits or petrol, be poured into the hand, the latent heat absorbed from the hand by the evaporation of the liquid will be noticeable.

The temperature at which the change from liquid to gas takes place is known as the boiling point. The boiling point of a substance is not constant, but depends on the pressure at which the change of state takes place.

A suitable gas can be compressed to such a pressure that its boiling point is above the temperature of the sea water, and by passing the gas at this pressure through a coil cooled by sea water, the gas can be liquified, giving up latent heat to the water. If the liquid so formed is admitted to a coil in a refrigerating chamber, and if the pressure in this coil is so adjusted that the boiling point of the liquid is below the temperature of the air in the chamber, the liquid will evaporate, receiving latent heat from the air surrounding the coil. To bring about the transfer of latent heat from the air in the cold room to the refrigerant and from the refrigerant to the sea water, the pressure in the low-pressure part of the system must be such that the liquid will boil at about 15° F. below the temperature of the air in the cold chamber, and the pressure in the high-pressure part of the system such that the gas is condensing at a temperature 10° F. to 15° F. above the temperature of the sea water. To facilitate the maintenance of the correct pressures, the pressure gauges on the system have two scales, one scale showing the pressure, and the other the boiling points of the refrigerant at these pressures.

Refrigerants.—The ideal refrigerant is a gas which can be liquified at a reasonable pressure, has a high latent heat of evaporation, is not poisonous or inflammable, and has no chemical action on the metals in common use. Some of the properties of the refrigerants in common use, and the pressures in pounds per square inch necessary in order that the gas may be liquified at 80° F. and the liquid evaporated at 0° F., are given below :—

Sulphur dioxide	SO_2	poisonous, not inflammable	45 and 9 p.s.i.
Methyl chloride	$C H_3Cl$	anaesthetic, inflammable	72 and 4 p.s.i.
Freon	$C Cl_2F_2$	non-poisonous, not inflammable	84 and 9 p.s.i.
Ammonia	NH_3	poisonous, inflammable	138 and 16 p.s.i.
Carbon dioxide	CO_2	non-poisonous, not inflammable	950 and 294 p.s.i.

Of the above five refrigerants, the two in most common use in H.M. ships are CO_2 and methyl chloride. Freon, which is the safest of all refrigerants, at present has to be obtained from abroad, it is used in submarines and is coming into use for surface ships. Ammonia is only used in a few of the older ships, and on account of the unpleasant effects of even a small leak of this gas between decks, ammonia machines are generally fitted on the upper deck. Ammonia machines are fitted with a drenching system for use in emergency, this gas being very soluble in water. Methyl chloride is not classed as poisonous, but the breathing of this gas will cause insensibility. As methyl chloride has not a very pronounced odour, a small amount of a chemical with a strong smell is sometimes added, in order that a slight leak may be noticeable.

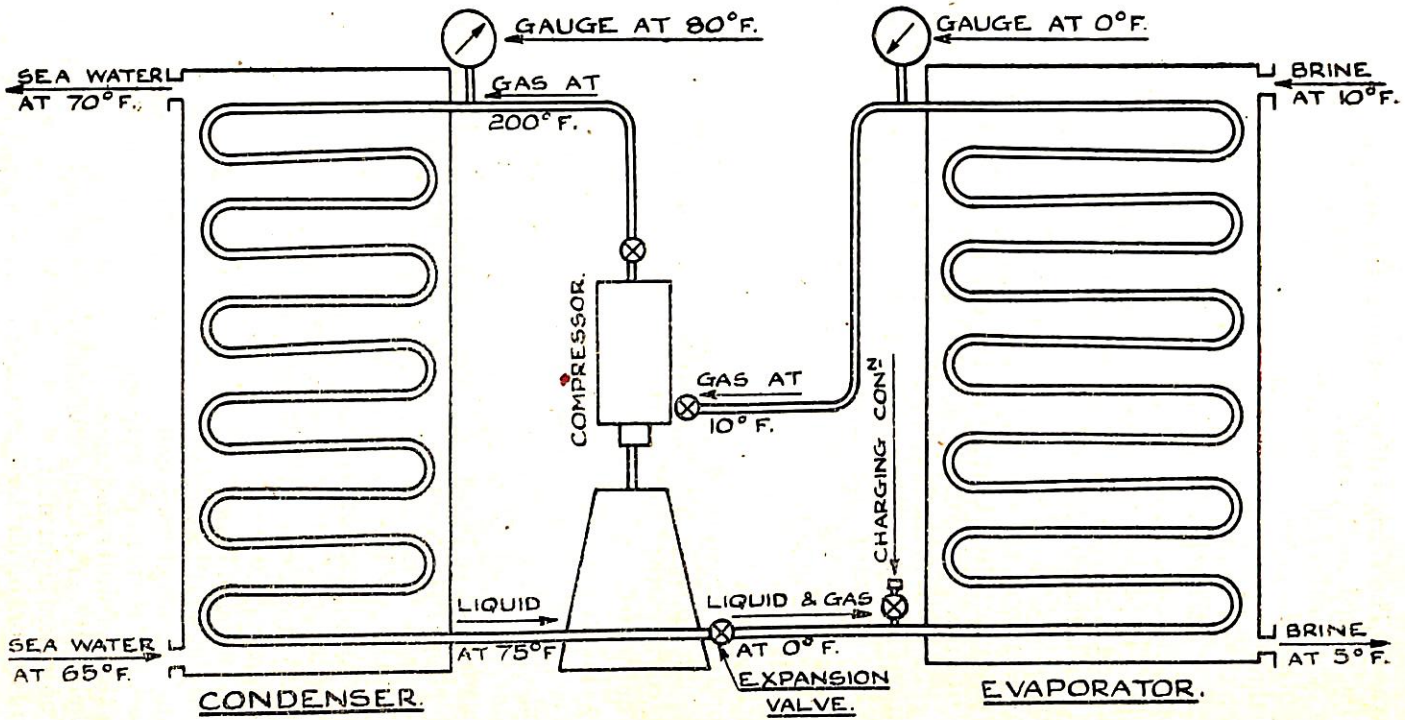
Refrigerants for charging and topping up machines are supplied in steel cylinders, or flasks, in the form of liquid under the pressure of their own gas. The pressure in the cylinder will depend on the temperature, and they must be stowed in a cool place and never left exposed to the direct rays of the sun. Each cylinder has stamped on it its weight when empty, so that the amount of refrigerant in a cylinder can be ascertained by weighing it. The cylinders are painted a distinctive colour to indicate which refrigerant they contain. If the refrigerant is poisonous, a yellow band is painted round the neck of the cylinder, and if the gas is inflammable, the cylinder will have a red band.

Gas circuit.—A diagrammatic sketch of a refrigerating machine for cooling brine is shown in Fig. 38, the arrows indicating the path of the refrigerant, the cooling water and the brine. The temperatures marked on the sketch are roughly those that should occur when the machine is adjusted to give the best results when running with a sea-water temperature of 65° F. and a temperature in the refrigerating chamber of about 16° F.

Compressor.—The compressor is generally single acting, and is driven by an electric motor through a belt, or through a pinion and gear wheel. A belt drive gives quieter running; to reduce the noise of a gear drive raw hide, compressed paper or composition pinions are used. The details of the compressor depend on the refrigerant used and the compression pressure necessary to liquify the gas.

For freon and methyl chloride a trunk piston type of compressor is used, and the bottom of the compression cylinder is open to the

FIG: 38.



REFRIGERATING MACHINE.

(8896/2205)W

crank case. The refrigerating gas from the evaporator or cooling coils is admitted to the crank chamber, and passes into the compressor cylinder through a non-return valve in the piston. A sealing ring is fitted, to prevent the escape of gas where the driving shaft passes through the wall of the crank case.

With CO_2 the pressures are much higher and the gas in the compressor is, therefore, confined to the cylinder, by using a crosshead type of compressor with a gland at the bottom of the cylinder. This gland is packed with special packing rings supplied by the makers, and is fitted with an oil seal to prevent the escape of gas. The oil seal is maintained by periodically forcing a small quantity of oil into the cylinder from an oil bottle on the compressor. High-pressure gas from the discharge side of the compressor is used to force the oil into the bottom of the cylinder.

Lubrication.—The bearings of the compressor are lubricated by oil splashed up from the bottom of the crank chamber. The makers instructions must be followed as to the level of oil to be maintained in the crank chamber, and attention must be paid to the lubrication of the motor bearings. Mineral non-freezing oil should be used where the oil is in contact with the refrigerant, *i.e.*, in the crank chamber of freon and methyl chloride machines and in the compressor cylinder of CO_2 machines. Special mineral oil should be used for the lubrication of other parts. In CO_2 compressors the gland sealing oil provides lubrication for the piston, and any oil discharged with the gas is intercepted by an oil separator, and blown out of the system once a watch. In freon and methyl chloride compressors some of the oil in the crank case is splashed on to the cylinder walls, and passes round the circuit, returning to the crank chamber with the gas.

Oil or grease should be applied to the pinions of geared compressors when these pinions are made of Fabroil, but for raw hide and compressed paper pinions dry graphite only should be used.

Condenser.—In all the larger refrigerating machines fitted in ships, sea water is used to cool the gas after compression, but in domestic refrigerators air cooling is employed.

For water-cooled condensers the cooling water may be supplied, either by a pump driven off the compressor crank shaft, by a separate electrically-driven pump, or it may be taken from the firemain system. Thermometers are fitted to show the temperature of the water entering and leaving the condenser. An air cock is fitted to release any air which may collect at the top of the condenser shell. It is possible that some hydrogen, formed by chemical action between the sea water and metal of the condenser, may be present in the shell. When opening the air cock, care must be taken that there is no naked light near.

A circulation of air for air-cooled condensers is provided by a

fan, driven by a belt from the electric motor operating the compressor.

Safety disc or cut-out switch.—A failure in the supply of cooling water to the condenser might lead to a dangerous rise in pressure in the compressor and condenser.

In CO_2 machines there is a hole in the compressor head which is blanked by a thin nickel disc. In the event of an undue rise in pressure, this disc will burst, and allow gas to blow to the atmosphere. Should this occur, the compressor should be stopped and the discharge valve shut. Safety discs are renewed every year, to guard against the failure of a disc due to deterioration.

Freon and methyl chloride machines are fitted with a safety cut-out switch, which stops the electric motor if the pressure in the condenser should rise above that at which the safety device is set.

Expansion valve.—The rate at which the liquid refrigerant is allowed to pass from the condenser to the evaporator is controlled by a valve, known as the expansion or regulating valve. It is by means of this valve that the correct pressures are maintained in the condenser and evaporator. Closing the valve a little will increase the condenser pressure and reduce the pressure in the evaporator. After adjusting the pressure in the evaporator, so that the temperature of the gas is about 10° F. below the temperature of the brine, or 15° F. below the temperature of the cold room in the case of direct expansion machines, the pressure in the condenser should be high enough to give a gas temperature in the condenser coil of 10° to 15° F. above that of the circulating water discharge. If the condenser pressure is too low, it will be necessary to increase the amount of refrigerant in the circuit. With CO_2 machines the expansion valve is controlled by hand, but with freon and methyl chloride machines this valve is controlled automatically and can be set to maintain a constant pressure in the evaporator coil.

Charging.—A connection is provided on the suction side of the compressor, to which a cylinder of refrigerant can be connected by means of a flexible metallic hose provided. When charging, the cylinder should always be vertical with the valve uppermost, so that the refrigerant will pass into the circuit as gas and not as liquid. The liquid in the cylinder will become very cold due to evaporation, and some considerable time will be required for all the liquid to vaporise. By hanging the cylinder on a spring balance, the weight of refrigerant that has been passed into the circuit can be ascertained. To get the utmost out of a cylinder, before closing the valve the compressor should be run for a few minutes with the expansion valve closed.

It is important that there should be no air or water in the circuit. If air is present in the circuit, the temperature readings on the pressure gauges will be incorrect and the efficiency of the machine will

be reduced, while water will freeze and choke the circuit. When charging an empty machine, the air is blown out by first breaking a joint on the suction side of the compressor and blowing gas through the evaporator with the expansion valve shut, and then blowing gas round the whole circuit with the pipe on the liquid side of the expansion valve disconnected. To intercept any water that may be in the cylinder, freon and methyl chloride machines are charged through a gas drier provided for this purpose. These driers are filled either with anhydrous calcium chloride or with alumina. The absorptive property of alumina may be restored by baking in an oven, but calcium chloride should be thrown away after use and a new charge used when the drier is again required. A cylinder of CO_2 may be tested for water by standing it for some hours with the valve at the bottom, and then blowing out any water present.

In some of the smaller machines the pressure gauges on the circuit are not kept permanently shipped. These gauges should always be in use when charging or topping up. The final adjustment of the quantity of refrigerant in the circuit should be carried out with the machine running, and the expansion valve set to give the required pressure in the condenser and evaporator.

Liquid cooler.—Fig. 38 shows the circuit used for the easily-liquifiable refrigerants, and also for CO_2 in temperate climates. For a CO_2 machine to give satisfactory results with sea water temperatures above 70° F., it is necessary to incorporate in the circuit a fitting known as a liquid cooler or pre-cooler.

The drop in pressure at the expansion valve causes some of the liquid refrigerant to vaporise before it reaches the evaporator. The higher the temperature of the liquid leaving the condenser, the greater will be the proportion which evaporates at the expansion valve, and the smaller quantity of latent heat received from the brine or cold chamber. If all the refrigerant is not liquified in the condenser, as may be the case with CO_2 when the sea water temperature is high, there will be a still greater falling off in the cooling effect. The liquid cooler, which is fitted between the condenser and the evaporator of CO_2 machines, separates the gas from the liquid, and a float operated valve allows only liquid refrigerant to pass on to the evaporator. The gas separated in the liquid cooler returns to the compressor, being admitted to the cylinder through ports uncovered by the piston at the end of the suction stroke. The compressor will now discharge to the condenser both the gas withdrawn from the evaporator during the suction stroke and the gas admitted from the liquid cooler at the end of this stroke. The pressure in the liquid cooler should be slightly greater than the pressure in the evaporator coil, and it can be adjusted by regulating a valve on the inlet side. A table, showing the liquid cooler pressure to give the best results with any particular condenser and evaporator

pressures, is supplied by the makers of the machine. Some evaporation takes place in the liquid cooler and this causes a reduction in the temperature of the liquid, hence the name liquid cooler. Provision is made so that the liquid cooler can be by-passed when it is not required. The lower the sea water temperature, the smaller is the gain by using the liquid cooler.

Evaporator.—In the refrigerating machines fitted in modern ships, heat is transferred direct from the air in the refrigerating chamber or magazine cooler to the cold refrigerant, and brine is only used in those machines used for making ice. In the older ships the refrigerant is vaporised in a coil, surrounded by brine in cylindrical container called the evaporator. The cold brine is circulated by an electrically-driven centrifugal pump through cooling coils in the refrigerating chambers, or through the tubes in the magazine coolers.

Brine.—The brine used in a refrigerating machine is made by dissolving sufficient calcium chloride in fresh water to give a solution whose density at 60° F. is 40 degrees on a Twaddell hydrometer. The freezing point of this solution is minus 8° F., *i.e.*, 40° F. below the freezing point of pure water. For brine of the required density about 4 lb. of commercial calcium chloride will be required for each gallon of brine made. The brass hydrometer used for distilling machinery must not be used for taking the density of brine for refrigerating machinery, as the scale on this hydrometer is quite different to the scale on a Twaddell hydrometer.

Enough soda should be added to the brine to render it just alkaline, and it should be tested periodically to ascertain if the addition of more soda is necessary to maintain it in this condition.

Precautions.—Great care must be taken to prevent leakage of gas from joints, etc., as not only will this entail a loss of refrigerant, but also a large accumulation of even those refrigerating gases not classed as poisonous may prove fatal to anyone in or entering the compartment. A service respirator does not afford protection against the refrigerating gases, and if it should be necessary to enter a compartment in which an escape of gas has occurred, a pattern 230 breathing apparatus should be worn.

All the refrigerating gases except ammonia are heavier than air. The machinery spaces are therefore ventilated by an exhaust fan which takes its suction from the bottom of the compartment. To give warning of an accumulation of gas a lamp must be kept burning on the deck of the machinery compartment, a candle lamp being used in the case of non-inflammable gases, and a safety lamp in the case of inflammable gases. A dangerous concentration of freon or CO_2 will extinguish a candle lamp, while with methyl chloride a cap will be noticeable above the flame of a safety lamp.

Before entering a refrigerating machinery compartment which

has been closed down, or the refrigerating room of a direct expansion machine, the compartment is to be tested for the presence of gas. Such a compartment should not be entered without taking the precaution of having a second person in attendance outside the compartment.

205. Refrigerating Rooms.—Whereas meat, fish, butter and milk are best kept at a temperature well below the freezing point of water, it is generally recommended that vegetables, fruit, cheese and eggs should not be frozen. Separate refrigerating rooms are therefore provided for those articles of food which should be kept frozen and for those which should be kept cool but not frozen. The meat or cold rooms should be kept at a temperature of between 16° and 18° F., while the vegetable or cool rooms are generally kept at about 32° F. Valves are fitted by means of which the quantity of refrigerant or brine passing through the coils in each room can be adjusted. Refrigerating rooms should not be opened more than twice a day, and then for not more than 15 minutes at a time. The temperature of a meat room, when opened for the removal of some of the contents, should not be allowed to rise above 26° F. A thermometer tube is fitted in each room, so that the temperature of the room can be ascertained without opening the door. Modern ships also have distant reading thermometers in the machinery compartment, which show the temperature of each refrigerating chamber; these thermometers are not generally accurate, and they should therefore be compared from time to time with the thermometers in the thermometer tubes.

Moisture from the air in the refrigerating rooms collects on the cooling coils in the form of snow. This snow interferes with the transmission of heat from the refrigerant or brine to the air, and it should be scraped off when the coating becomes thick. Coating the cooling coils with a compound called Kilfrost facilitates the removal of snow.

206. Automatic Refrigerators.—Domestic refrigerators, and other small refrigerating machines, are fitted with a device designed to maintain the temperature in the food chamber between certain limits. The expansion and contraction of a liquid in a tube, terminating in a bulb in the cold chamber, operates a spring-loaded bellows, which in turn operates a switch for the compressor motor. When the temperature in the chamber rises to the upper limit, the expansion of the liquid compresses the bellows against the spring, and starts the motor, and when the machine has brought the temperature down to the lower limit the compressor stops. The temperatures at which the machine stops and starts can be adjusted by altering the compression of the spring.

207. Magazine Cooling and Air Conditioning.—With the cordite supplied to ships up to a few years ago a slow deterioration took place at temperatures of over 70° F., and cooling arrangements were therefore fitted to the magazines in cruisers and larger ships. With the cordite now supplied no appreciable deterioration takes place up to 90° F., but it has been found that at temperatures below this, cordite, if not enclosed in an airtight case, gives off a harmful gas. Magazines in which men handle cordite in non-airtight cases are therefore now fitted with cooling arrangements, even when cooling is not required to prevent deterioration of the cordite.

Where the cooling arrangement is fitted to prevent deterioration of the cordite, it is known as a magazine cooling plant, but when fitted to prevent the men working in the magazine suffering from headaches, it is known as an air-conditioning plant. In either case the arrangement consists of a fan, a magazine cooler, and a refrigerating machine to provide a supply of cold gas or brine for the cooler. When the cooler is in use, the fan draws air from the magazine, passes it through the cooler, and back to the magazine. When the cooler is not required, the magazine can be ventilated by changing over air flaps on the suction side of the fan, and opening water-tight shutters on two trunks to the upper deck, so that the fan pumps fresh air through the magazine. In action these water-tight shutters must be closed, and the cooling or air-conditioning plant brought into use.

Atmospheric air contains water vapour, and if this air is cooled below a certain temperature some of this water vapour will condense. There is, therefore, likely to be some condensation on the air side of the cooler, and a drain is fitted so that this water can run off into a receptacle.

In the magazine cooling plants fitted in the older ships, CO_2 machines are used to cool the brine circulated through the magazine coolers, and these machines are controlled by hand. In modern ships direct expansion freon machines are fitted and the control is automatic.

208. Hydraulic Pumping Engines.—In all battleships the machinery for operating the large guns is worked by hydraulic power, supplied by steam-driven hydraulic pumps. There is usually one hydraulic pumping unit per turret, but the latest battleships have an additional pumping unit, to allow for one unit being under repair. The hydraulic systems of each turret are cross connected through a hydraulic main, so that any pumping unit can supply power to any turret. For each pumping unit a tank is fitted, from which the pump takes its suction, and to which the hydraulic fluid exhausted from the turret machinery returns.

The smaller guns, fitted in aircraft carriers and cruisers, are

operated partly hydraulically and partly by hand. The hydraulic power for each twin mounting is supplied by a separate electrically-driven variable-stroke pump, and the engine-room department is not concerned in the operation of these pumps.

The guns of modern destroyers also require hydraulic power. Variable-stroke pumps are fitted, and in some ships they are placed in the main machinery spaces and driven by a steam turbine.

The lifts for raising the aircraft to the flight deck are operated by hydraulic power in some carriers, and hydraulic power from the same system is used for raising and lowering the masts, operating the water-tight seal around the lift at the flight deck, etc. Where the lifts in a carrier are electrically operated, a small hydraulic pump is fitted for the masts, deck seal, etc.

Water is the cheapest fluid to use in a hydraulic system, but pure water has no lubricating property, and is liable to freeze in cold climates if any part of the system is in an exposed position. Freezing will not only put the hydraulic machinery out of action, but the increase in volume that takes place when water turns into ice will cause pipes, cylinders, etc., to be fractured.

Mixing a small quantity of argoline oil with distilled water provides a fluid which has sufficient lubricating properties for the cylinders of reciprocating engines and pumps. Such a mixture is used in the hydraulic system of battleships, and in aircraft carriers with hydraulically operated lifts. The quantity of argoline oil added has recently been increased from $3\frac{1}{8}$ gallons to 5 tons of water, to 1 part of argoline oil to 60 parts of water. The addition of this small quantity of argoline oil lowers the freezing point of water slightly. In aircraft carriers, where a separate system is fitted for the operation of masts, deck seals, etc., on the flight deck, a mixture of 50 parts of glycerine to 50 parts of water is used. This mixture is safe against freezing down to minus 20° F.

Cruisers and destroyers have no hydraulic main, and the systems require a relatively small quantity of fluid. In these systems special mineral lubricating oil is used.

The hydraulic pumps in H.M. ships are of three types :—

(1) *Reciprocating pumps.*—In the older battleships horizontal reciprocating pumps were fitted. Each unit consists of two pumps, with the crossheads connected to a crank shaft with the cranks at 90 degrees to one another, so that one pump is at mid stroke while the other is passing over the dead centre. The pumps are single acting, but they are so designed that they deliver half the capacity of the barrel on one stroke and the other half on the next stroke. In this way a steady discharge is obtained.

A double compound tandem steam engine supplies the power for the two pumps. Connected to each crosshead is

the H.P. piston rod and the two L.P. piston rods of a horizontal compound engine, with the H.P. cylinder situated in line with the L.P. cylinder and between the two L.P. piston rods. The speed of the engine must be regulated, to maintain a constant delivery pressure with a varying demand for hydraulic power. A constant-pressure governor is fitted, which regulates the supply of steam to the engine as necessary to keep the pump discharge pressure constant. The steam-control valve is also connected to a centrifugal governor, which prevents the engine exceeding the maximum speed for which it is designed.

(2) *Centrifugal pumping unit.*—Centrifugal hydraulic pumps driven by a steam turbine are fitted in some modern battleships and aircraft carriers. These pumps are lighter, and require less upkeep, than the large twin reciprocating pumps fitted in the older ships. Each pumping unit consists of a small pump, of sufficient capacity to provide the hydraulic power required when turret is standing by, and a larger pump, which is running idle under these conditions, and automatically comes into operation when more power is required than the small pump can provide. The small pump is known as the maintenance pump, and the large pump as the main pump.

The maintenance pumps of the units in some ships are small reciprocating steam pumps, but it is now the practice to fit small turbine-driven centrifugal pumps.

The maintenance pump and the main pump are each fitted with a hydraulic pressure governor, the governor on the maintenance pump being set at 1,200, and that on the main pump at 1,100 lb. per square inch. The maintenance pump will maintain a pressure of 1,200 lb. in the system, while the output required is within the capacity of this pump. The pressure in the system acts on the hydraulic governor of the main pump, and keeps the steam valve of this pump closed as long as the maintenance pump is capable of maintaining a full pressure in the system, a sufficient leakage being provided past the steam valve of the main pump to keep this pump running idle. When the output increases beyond the capacity of the maintenance pump, the pressure in the system falls below 1,100 lb. The pressure governor of the main pump will then operate and open the steam valve of this pump. The main pump will then speed up, and as soon as the pressure in the pump exceeds the pressure in the system a non-return valve on the pump discharge will lift. The system will be supplied by the main and maintenance pumps as long as the draw off from the system is such that the pressure in the system does not exceed 1,100 lb. When the draw-off falls,

so that it is again within the capacity of the maintenance pump, the pressure in the system will rise to 1,200 lb. and close the steam valve of the main pump. A small by-pass is fitted from the discharge side of the main pump back to the tank, to provide a circulation through the pump while it is idling, and so prevent overheating. To prevent an undesirable rise in temperature in the tank, either the fluid by-passed is passed through a cooler, or a small electrically-driven pump is fitted to circulate fluid from the tank through a cooler and back to the tank.

(3) *Variable-stroke pumps.*—The hydraulic pumps fitted in some ships are of the Williams Janney or Hele Shaw type. When these pumps are situated in the main machinery compartments, or are driven by a steam turbine, the engine-room department are responsible for their operation. The pump is driven at constant speed and a hydraulic pressure governor is fitted, which by altering the stroke, varies the output as necessary to maintain a constant discharge pressure. Lubrication of the pump mechanism is ensured by keeping the inside of the pump casing full of oil. When the fluid being pumped is oil, any leakage past the pump plungers to the inside of the casing will have no ill effects on the lubrication. If the fluid being pumped is water, provision must be made to prevent leakage of water contaminating the lubricating oil. In the Williams Janney pumps fitted in some battleships the pump casing is divided into two, and only that portion of the casing which contains the pump actuating gear and mechanism for varying the stroke is kept full of oil. Leakage of water past the pump plungers, together with any oil leakage, drains from the other portion of the pump casing to a tank, where the oil and water separate by gravity.

The exhaust steam from twin-reciprocating hydraulic pumps is led to the auxiliary exhaust range, but each of the turbine-driven pumping units in battleships has its own condenser, with a circulating and extraction pump driven from the turbine driving the main pump. The exhaust from a turbine-driven maintenance pump is normally led to the L.P. stage of the main pump turbine, but the maintenance pump can exhaust to the auxiliary exhaust range if it is desired to use this pump without running the main pump. For a reciprocating maintenance pump a drain cooler is fitted, and the condensate is passed through a grease filter. Cooling water for the drain cooler can be taken from circulating pump driven from the main pump, or from the fire main if it is desired to run the maintenance pump only.

209. Compressed Air.—Compressed air is used in warships for a number of different purposes, for each of which air is required at some particular pressure. In general the requirements can be divided into two groups, those requiring air up to a pressure of 120 lb. per square inch, and those requiring air at a higher pressure. In cruisers and larger ships two separate compressed-air systems are fitted, a L.P. system supplied by a general service air compressor, and a H.P. system supplied by two or more H.P. air compressors. In smaller vessels the requirements for L.P. air are met by taking a supply from the H.P. system through a reducing valve, or when a considerable reduction in pressure is necessary, through two reducing valves in series.

High-pressure air is required for :—

(1) Charging the air vessels of torpedoes to 3,000 lb. per square inch.

(2) Supplying air to turrets for the air blast to guns and for charging recuperators. Air is required at a pressure of 1,200 lb. per square inch, but in order to have a reserve for the air blast of turret guns, air is supplied at a pressure of 3,500 to 4,000 lb. to an air bottle in each turret. When no air blast is fitted, the recuperators are topped up periodically from the H.P. air system through a reducing valve and flexible hose.

(3) Charging the air starting bottles of diesel generators. These bottles are generally charged to a pressure of about 400 lb., but in some ships the bottles are designed to be charged to a higher pressure and the engine supplied through a reducing valve.

Low pressure air is used for :—

(1) Testing condensers by air pressure to 10 lb. per square inch.

(2) Air jet for the external cleaning of boilers.

(3) Emptying boilers to the sea by connecting the air cock to L.P. air system.

(4) Forcing of petrol and aviation spirit from storage tanks in hold to connections on the upper deck. Air is supplied by electrically-driven or hand-operated single-stage compressor, with an alternative supply from L.P. air service where fitted.

(5) Alternative supply to oil-fired galleys, where the oil burners are of the type in which the oil is sprayed by air.

(6) Air pressure test of water-tight compartments, when a sufficient pressure cannot be obtained by means of a ventilation fan ; pressure not to exceed 2 lb. per square inch.

(7) Expelling the acid from the container of C.S.A. smoke-making apparatus.

(8) Pneumatic tools in ships to which these tools are supplied.

Air is also used for the pneumatic transmission of written messages from the bridge to wireless offices. Electrically-driven single-stage compressors are fitted for this purpose and there is no alternative connection to the L.P. air main.

210. Air Compressors.—When air is compressed its temperature rises. In compression ignition oil engines a temperature of about 1,000° F. is attained by compression to 500 lb. per square inch, and compression to higher pressure in a single stage would produce even high temperatures. Such high temperatures would be most undesirable in an air compressor. Compression up to about 120 lb. per square inch can be carried out satisfactorily in a single stage if the compression cylinder is fitted with a suitable water jacket. For higher pressures the compression is carried out in two or more stages, and the air is cooled after each stage. Atmospheric air contains a certain amount of water in the form of vapour. When a volume of air at atmospheric pressure is compressed to a smaller volume, and cooled down to its original temperature, some of the water vapour present will condense. Provision must be made to separate and remove this water, and any lubricating oil used in the compressor cylinders, from the compressed air.

H.P. air compressors.—In ships where air is required at a pressure of 3,000 lb. per square inch for torpedoes or for turrets, two or more four-stage compressors are fitted for charging air bottles to 3,500 or 4,000 lb.

In some small ships, which neither carry torpedoes, nor require blast air for guns, but in which starting air is required for diesel generators, a small two-stage compressor is fitted. These compressors are capable of pumping to a pressure of 1,200 lb. per square inch, and are driven by a single cylinder oil engine. In addition to charging the starting air bottles, they are used for the periodic topping up of the recuperators of the guns.

The four-stage compressors fitted in the older ships are open steam-driven engines. The plungers of two double-acting compressor cylinders are attached to a common crosshead, which is driven by two steam cylinders fitted below the air cylinders. The two air plungers are stepped, the space above the larger plunger forming the first stage, while the smaller annular area below forms the second stage. Similarly, the area above the smaller plunger is the third stage, while the annular area below forms the fourth stage. Each stage is fitted with an inlet and discharge valve, and the inter coolers and after cooler are in the form of coils of copper tubing, fitted inside the common water-jacket surrounding the air cylinders. The plungers are of bronze or gunmetal and work in gunmetal

barrels, being made airtight by means of fibre packing rings. A little special mineral oil is admitted by means of a drip lubricator to the first stage, to act as a lubricant for both cylinders ; a little distilled water is also admitted to keep the fibre packing rings soft.

A modern four-stage compressor has four air cylinders, arranged in pairs, tandem wise, above a two-throw crankshaft, which revolves in an enclosed crank case. The crank shaft is driven by an electric motor or steam turbine through gearing, or by a separate compound-steam engine. A connecting rod from each crank actuates two plungers, the smaller plungers of the two high pressure stages being attached to the top of the first- and second-stage plungers. Each stage is single acting, air being drawn in through an inlet valve on the down stroke, compressed on the up stroke, and discharged through a spring-loaded non-return delivery valve into a cooler. An air filter is fitted on the inlet to the first stage. The compression end of each cylinder has a water jacket, and the cooling coils or tubes are fitted in two separate casings, one casing containing the first- and second-stage inter coolers, and the other the third-stage inter cooler and the after cooler. A gear wheel pump, driven off the crank shaft, circulating sea water through the jackets and cooler casings. A flow indicator is generally fitted to show if the water is circulating correctly. Should the supply of cooling water fail the compressor must be stopped at once. At the outlet end of each inter-stage cooler is a small chamber, known as a drain bottle, in which water condensed due to the compression and cooling of the air is collected and drained to the bilge. On account of the small clearances in the air cylinders it is very important that a compressor should be turned by hand with the drains open for one or two revolutions before starting. Cast-iron liners are fitted to the cylinders, and the packing rings are also of cast iron. Oil is supplied to the bearings of the compressor from a sump at the bottom of the crank case, by a pump driven from the crankshaft. A strainer, a pressure gauge, and a valve for adjusting the oil pressure are fitted on the discharge side of the oil pump, and a dip stick is provided for checking the level of oil in the sump. The first- and second-stage cylinders are open to the crank chamber, and oil thrown up by the crank provides ample lubrication for these cylinders. For the third- and fourth-stage cylinders two oil cups, and ratchet operated mechanical lubricators for forcing in the oil, are fitted.

The cups should be filled with admiralty compound oil. The rate of supply can be adjusted and should be in accordance with the instructions in the maker's handbook.

Each stage of a multi-stage compressor is fitted with a pressure gauge and a relief valve. The correct working pressure in each stage, when the compressor is pumping against the maximum

designed pressure, is stamped on a brass plate on the engine. An excessive pressure in any stage indicates that there is a leakage from a higher pressure stage; if this occurs, the engine should be stopped and the defect made good.

From the after cooler the air passes into the top of a vertical steel tube, known as a separator column. At the bottom of this column are two drain valves, one a fine thread valve which is adjusted so as to just drain away the water and oil separated from the air, and the other an emergency drain valve which should be opened every ten or fifteen minutes to ascertain that the separator is clear of liquid. The separator columns in some of the older ships have float controlled automatic drains instead of a fine thread hand-operated valve. The air passes from the top of the separator column through an air outlet valve to the H.P. air main.

At points where air is tapped off from the main for charging torpedoes, etc., a smaller column, known as a charging column, is fitted. The charging columns are fitted with a drain, and intercept any water condensed after the air has passed through the separator column.

Drain valves are also provided on storage bottles, where these are fitted for the storage of high-pressure air, and these bottles should be drained periodically.

If it is required to level up the pressure in storage bottles this should be done gradually. A sudden rise of pressure in an air bottle or pipe may cause a sufficient rise in temperature to ignite any oil present.

General service air-compressors.—Cruisers have one, and larger vessels two, L.P. air compressors, for supplying air to the low-pressure services mentioned in Article 209.

The L.P. air-compressors in the older ships are open steam-driven engines with a two-stage air-cylinder fitted above a steam cylinder.

In modern L.P. air-compressors, air is compressed in a single stage to 120 lb. per square inch. The plungers of two single-acting air cylinders are connected to a two-throw crank shaft, which revolves in an enclosed crank case, and is driven by an electric motor. Each cylinder is water-jacketed and fitted with a non-return inlet and delivery valve. Air is drawn in through an air filter and discharged through a cooler to a large air receiver. A spring loaded air relay valve on this receiver lifts when the pressure in the receiver reaches 120 lb. per square inch, and admits air to two plungers above the air-inlet valves. The depression of these plungers prevents the air inlet valves closing, and no more air will be pumped into the receiver until the pressure drops and the air relay valve closes. An extension spindle from each of the plungers allows of this unloading device being operated by hand.

A gear wheel pump, driven by a belt from the shaft between

the electric motor and the compressor, circulates sea water through the air cylinder jackets and through the casing of the air cooler. On the air outlet end of the cooler is a chamber, in which water is separated from the air and drained off through a drain cock. There is also a drain on the air receiver. Some compressors have a small lubricating oil pump, while in others the bearings are lubricated by oil splashed up from the bottom of the crank case by an oil thrower on each crank-pin bearing. Before starting the compressor, any water which has collected at the bottom of the crank chamber should be drained off, and special mineral oil added to bring the oil level up to, but not above, the mark on the dip stick. The engine should then be turned one revolution by hand.

CHAPTER XV.

INTERNAL COMBUSTION ENGINES.

211. I.C. Engines—General.—Internal-combustion engines derive their name from the fact that the fuel is burnt in the working cylinder. Their development dates from the latter half of the nineteenth century, that is about a century later than the steam engine. The earliest I.C. engines used coal gas. When petroleum fuels became available, engines were developed to run on petrol and paraffin, and later, at the end of the nineteenth century, the oil engine was introduced.

There are to-day many different types of I.C. engines, from those of a few horse-power for propelling small boats and vehicles, to engines of up to 15,000 horse-power, fitted in large motor vessels. The fuel used may be a combustible gas, a volatile liquid fuel such as petrol, or a high flash-point petroleum oil known as diesel oil; all marine engines use liquid fuel.

While there is a wide difference in the details of the different types of I.C. engines, there are certain principles which are common to them all. A charge of air is compressed in a cylinder, by the inward movement of a piston connected to a crank. The energy required to compress the air is provided by turning the engine by hand, or by other means when starting, and by the momentum of a rotating fly wheel when the engine is running. The temperature of the air rises during compression, and the increase in temperature depends on the ratio of compression, *i.e.*, the ratio of the volume of air before compression to the volume after compression. At the end of the compression stroke, as the crankpin passes over the dead centre, and commences what is known as the working stroke, the combustion of the fuel causes a further and larger increase in the temperature of the air. The combustion must be timed to take place at the right moment. In gas engines and petrol engines the fuel is present in the cylinder during the compression stroke, and combustion is started by an electric spark. In these engines the ratio of compression must be sufficiently low to ensure that the temperature during compression does not reach the ignition temperature of the fuel. In compression ignition engines liquid fuel is injected into the cylinder at the end of the compression stroke, and the temperature of the compressed air must be high enough to ensure that the fuel will ignite.

Due to the increase in temperature, brought about by the combustion of the fuel, the pressure in the cylinder throughout the working stroke is greater than the pressure at corresponding points

during the compression stroke. The work done on the piston by the hot gases during the working stroke will therefore be greater than the work done in compressing the air, and the difference will be a measure of the useful work done in the cylinder. The rate at which useful work is being done in the cylinder can be obtained from an indicator diagram, and is known as the indicated horse-power. Some of the indicated horse-power is absorbed in charging the cylinder with air, expelling the exhaust gases, and in overcoming friction in the cylinder, bearings, etc., and the remainder constitutes what is known as the brake horse-power. The brake horse-power of an engine can be obtained by running the engine against a hydraulic brake in a testing shop and measuring the power absorbed by this brake.

At the end of each working stroke the cylinder must be cleared of the products of combustion, and a fresh charge of air introduced. This recharging of the cylinder may be effected in either of two ways, some engines working on what is known as a four-stroke cycle and others on a two-stroke cycle (*see* Articles 212 and 213).

With the exception of some of the large oil engines used for the propulsion of ships, all internal-combustion engines are single acting, that is, work is done only on one side of the piston. All small and medium-size engines are of the trunk piston type ; with one end of the connecting rod connected to the piston by the gudgeon-pin bearing, and the other end to the crank pin by the crank pin or big end bearing, the piston being made deep enough to take the lateral thrust. Double-acting, and large single-acting engines, used for the propulsion of ships, have piston rods with a slipper and guide, similar to steam reciprocating engines.

As the combustion of the fuel in the cylinder gives rise to gas temperatures in the region of 4000° F., it is necessary to provide some form of cooling for the cylinders and cylinder covers, and in large engines cooling arrangements must also be provided for the pistons. The cylinders of some of the smallest engines can be maintained at a reasonable temperature by air cooling, but the general practice is to use water-jacketed cylinders and hollow cylinder covers, through which water is circulated. The general practice for a small multi-cylinder engine is to form a number of cylinders in a single casting, which is cored to leave a hollow space around the walls of each cylinder. Another hollow casting, bolted on to one end of this cylinder block, forms a cover for all the cylinders. Ports are provided through which the cooling water can pass from the space around the cylinder walls to the hollow cylinder cover. In larger engines the walls of each cylinder are formed by a separate cylinder liner, fitted into a cast cylinder, so as to leave a space for the circulation of water around the outside of the liner.

212. Four-stroke I.C. Engines.—The majority of internal-combustion engines work on what is known as the four-stroke cycle. Between the end of a working stroke and the beginning of a compression stroke, two strokes of the piston are used to clear the cylinder of the products of combustion, and draw in a fresh charge. There is thus in each cylinder of a four-stroke engine one working stroke in every four. The sequence of the operations is as follows :—

(1) An induction stroke, during which a fresh charge is drawn into the cylinder through an inlet valve.

(2) A compression stroke, for the compression of the charge into the combustion space at the end of the cylinder.

(3) A working stroke, commencing with the combustion of the fuel, and continuing by the expansion of the products of combustion, which are released at the end of this stroke through an exhaust valve.

(4) The exhaust stroke, during which the products of combustion remaining in the cylinder are pushed out through the exhaust valve, which remains open until the end of this stroke.

Each cylinder of a four-stroke engine must have an inlet and exhaust orifice, and each of these must be opened and closed at the correct time, once every two revolutions of the engine. The induction and exhaust may be controlled, either by poppet valves or by a sleeve valve, the former being the more common method.

Poppet valves are spring-loaded non-return mushroom-shaped valves, which open into the combustion chamber. They are operated by cams on a shaft driven from the crankshaft, through gearing or by means of a chain drive, so that the camshaft revolves one revolution for every two revolutions of the crankshaft. There is generally one inlet and one exhaust valve for each cylinder, but high-duty engines often have two inlet valves, and also in some cases two exhaust valves.

In a sleeve-valve engine each cylinder is fitted with a close-fitting movable sleeve, inside which the piston reciprocates. At the combustion chamber end of the sleeve are a number of ports, and a reciprocating and turning motion is imparted to the sleeve, so that during the induction stroke some of the ports in the sleeve register with induction ports in the cylinder, while during the exhaust stroke other ports in the sleeve register with the cylinder exhaust ports. The sleeves are operated by a shaft, which revolves at half the speed of the crankshaft, so that each sleeve performs one cycle each two revolutions of the engine.

213. Two-Stroke I.C. Engines.—By employing a pump or blower to supply the air, or air and fuel mixture, under a slight pressure, it is possible to dispense with the exhaust and induction strokes,

and thus obtain one working stroke in every two. As the piston approaches the end of the working stroke, the pressure in the cylinder is released to the atmosphere, generally through ports in the cylinder uncovered by the piston. The fresh charge is admitted to the cylinder under sufficient pressure to expel the greater portion of the products of combustion remaining in the cylinder. This is known as scavenging the cylinder.

There will be a tendency for a certain amount of mixing of the fresh charge with the products of combustion to take place. Various means are adopted to reduce this mixing to a minimum, and to ensure that as far as possible the cylinder is filled with the fresh charge before the compression stroke commences. For the sake of simplicity it is a common practice to admit the fresh charge through ports on one side of the cylinder while exhausting through ports on the other side. The incoming charge must be prevented from passing direct to the exhaust ports by deflecting it to the combustion end of the cylinder, either by suitably shaping the top of the piston or by suitably shaped scavenge ports ; this is known as loop scavenge. In many modern types of two-stroke engine the fresh charge is admitted at one end of the cylinder, while the exhaust takes place from the other. While this through scavenge has the great advantage of reducing the adulteration of the new charge with exhaust gas, thereby improving the combustion as compared with the loop scavenge, it necessitates the provision of a mechanically operated valve, either for the inlet or for the exhaust. In what are known as opposed-piston engines, each cylinder has two pistons, which move in opposite directions ; and at the end of the working stroke the exhaust ports at one end of the cylinder are uncovered by one piston, while the inlet ports at the other end of the cylinder are uncovered by the other.

It is impossible to prevent some mixing of the old and new charges in the cylinder. By arranging that the volume of the charge admitted in a two-stroke engine is appreciably greater than the volume of the cylinder, it is possible to expel from the cylinder nearly all the exhaust gases, at the expense of losing through the exhaust port the surplus charge admitted. While such an arrangement is acceptable in the case of engines in which the fuel is injected at the end of the compression stroke, it cannot be employed for these engines when the fuel is admitted with the air. In two-stroke engines in which the fuel is admitted as a gas or vapour with the air, the volume of the charge admitted each stroke must be less than the volume of the cylinder, to avoid loss of fuel with the exhaust, and the reduction in power due to the adulteration of the fresh charge with exhaust gases must be accepted.

In most two-stroke oil engines the air, for scavenging and charging the cylinder, is supplied either by a reciprocating scavenge

pump driven from the engine crankshaft, or by a rotary blower. In small single-cylinder engines the reciprocating motion of the piston in the crank-case is commonly used to pump the fresh charge to the cylinder. Due to the large clearance volume, the crank-case does not form an efficient pump, and the volume of the fresh charge supplied each stroke will be appreciably less than the volume of the cylinder. Nearly all gas engines and petrol engines work on a four-stroke cycle. There are a few two-stroke petrol engines, and in these engines the use of the crank-case as a pump will provide as large a charge as can be used without the loss of fuel through the exhaust port.

214. Supercharging.—The power that can be obtained from an internal-combustion engine, can be increased by increasing the amount of air and fuel used in each cylinder each stroke. In the four-stroke engine, described in article 212, air is drawn into the cylinder from the atmosphere by the creation of a partial vacuum in the cylinder, and due to the short time available for the induction, it will not be possible to charge the cylinder to atmospheric pressure. By making use of a blower, to supply the air or air and fuel to the cylinder, it is possible to obtain an increase in power, in a suitably designed engine, of as much as 50 per cent. Such an operation is known as supercharging, or pressure charging.

215. Types of I.C. Engines.—Internal-combustion engines can be divided into the following three main classes :—

(1) *Gas engines.*—For small stationary engines coal gas from the town mains is commonly used as a fuel. Gas engines are not used in ships and are not in common use in vehicles. The gas required may be produced from coal or other solid fuel in a generator incorporated with the engine. This gas is known as producer gas and such plants are fitted in some heavy vehicles.

(2) *Carburettor engines.*—In these engines the necessary quantity of a volatile liquid fuel generally petrol, is mixed with the air as it is drawn into the cylinders through a carburettor. The mixture of vaporised fuel and air is ignited at the end of the compression stroke by an electric spark. Petrol engines are used for nearly all fast motor boats and for most road vehicles.

(3) *Compression ignition engines.*—Due to the large demand for petrol this fuel has commanded a higher price than the less volatile products obtained from the fractional distillation of petroleum. Towards the end of the last century internal-combustion engines were produced to use these heavier fuel

oils, which are not sufficiently volatile for use in a carburettor engine. These engines are often referred to as oil engines or heavy-oil engines, to distinguish them from carburettor engines in which the lighter and more volatile fuels are used.

The first successful oil engines were produced in this country towards the end of the last century. In these engines a jet of fuel was injected during the compression stroke into an unjacketed extension of the cylinder, known as the hot bulb. The heat imparted to the fuel and air by the hot bulb, together with the heat due to compression sufficed to ensure ignition of the fuel at the end of the compression stroke. It was necessary to heat the bulb with a blow lamp to start the engine. The compression pressure employed in these hot-bulb engines was only about 60 lb. per square inch; the efficiency was slightly less than that of carburettor engines, but they had the advantage of using cheaper fuel.

A few years after the introduction of the hot-bulb engine an oil engine was patented of a German named Diesel, in which a compression pressure of 500 lb. per square inch was used, the fuel being sprayed into the cylinder at the end of the compression stroke by a blast of H.P. air. Diesel's engine achieved a higher efficiency than either the carburettor or hot-bulb engines, but it was more expensive to build, and required a compressor to provide a continuous supply of H.P. pressure air for the blast injection of the fuel.

Both types of oil engine were built for some years, and development followed along two different lines. The makers of the cheap inefficient low compression engine gradually raised the compression and improved the injection system, while the makers of the expensive Diesel engine did away with the air compressor and lowered the compression pressure somewhat. Thus the two types merged into a third type, namely, the modern high-compression airless injection oil engine. The name diesel engine is commonly used for any internal-combustion engine which relies on the heat of compression to ignite the fuel, and the name semi-diesel has been used for engines employing a lower compression pressure and having a portion of the cylinder head unjacketed.

On account of the great accuracy necessary in the manufacture of the pumps, etc., for injecting the fuel, a compression ignition engine is more expensive than a carburettor engine, and due to the higher compression pressure employed, these engines are slightly heavier. The efficiency of a compression ignition engine is however much higher, and risk of fire is less with the less volatile fuel. Compression ignition engines are now employed for the heavier and slower ship's boats, for

all oil-driven electric generators, for submarines, and for the propulsion of a large number of merchant ships. In a few of H.M. ships, where the extra weight can be accepted, oil engines are fitted as the main propelling machinery. Light high-speed compression engines have recently been developed which are suitable for fast type motor boats, and these engines will gradually replace the petrol engines for these boats.

216. Carburettor Engines.—As mentioned in the previous article, carburettor engines are fitted in the majority of motor boats. The engines of the early motor boats supplied to H.M. ships were designed to run on mineral vaporising oil. This fuel, which is commonly called paraffin, is less volatile than petrol, but it can be vaporised more readily than the paraffin used for lamps. With mineral vaporising oil there is less risk of an accidental explosion or fire than with petrol, but in every other respect petrol is the more satisfactory fuel and is now in general use for ships' boats. Engines designed to be run on mineral vaporising oil can be run on petrol ; provision was made for these engines to be started on petrol and changed over to mineral vaporising oil when the engine was hot enough to vaporise this less volatile fuel. Petrol engines are fitted in nearly all the fast-type motor boats supplied to H.M. ships and these engines will not run on mineral vaporising oil.

The particular features of carburettor engines are the carburettor and the ignition system.

Carburettor.—14 lb. of air are required for the complete combustion of 1 lb. of petrol, and the function of the carburettor is to control the quantity of fuel admitted with the air, so that the proportion of fuel to air shall be at or near this ratio.

The carburettor is fitted at the inlet end of the induction pipe through which air is drawn into the cylinders. As the air passes through the carburettor it picks up petrol from one or more jets, which communicate with a float chamber, in which a constant level of petrol is maintained by a float-controlled needle valve. The level in the float chamber should be such that petrol does not flow from the jets when the engine is stopped. When the engine is running, the reduced pressure in the induction pipe causes sprays of petrol to issue from the jets. The speed of the engine is controlled by a butterfly valve, known as the throttle, in the induction pipe, on the engine side of the carburettor. Partial closing of the throttle reduces the weight of air and fuel drawn into the cylinders.

A pump operated by the engine pumps petrol from the storage

tank to the float chamber. This pump can be operated by hand to ensure a supply of petrol to the jets when starting the engine, and in some engines the needle valve can be raised to allow of the float chamber being flooded to a higher level for starting than is required when the engine is running.

The carburettor must maintain the correct fuel/air ratio at all speeds of the engine, and to accomplish this, it is necessary to have a jet whose opening varies with the speed of the engine, or to provide a number of jets. If the amount of petrol is appreciable less than one to fourteen, the combustion will be very slow, there will be a large drop in the power developed, and the mixture in the cylinder may still be burning when the inlet valve again opens, thus causing small explosions in the inlet pipe. These small explosions will cause puffs of mixture to be blown out through to the air inlet to the carburettor; this is known as "popping back." If the mixture is excessively weak, it will fail to ignite when the spark passes at the end of the compression stroke. An over-rich mixture may also fail to ignite, and it is uneconomical to supply a greater quantity of fuel than can be completely burnt in the air present in the cylinder.

When the engine is hot, the mixture receives heat from the walls of the inlet pipe, and from the inlet valve as it enters the cylinder, also the temperature of the mixture is raised still further during compression. With petrol this suffices to vaporise the fuel when the engine is running. When mineral vaporising oil is used, additional heat is supplied to the fuel/air mixture by passing it through a vaporiser, in which the mixture is heated indirectly by the exhaust gases from the engine.

When starting an engine from cold, only the more highly volatile fractions of the petrol will be vaporised, and to obtain a combustible mixture of petrol vapour and air it is necessary to increase the proportion of petrol to two or three times that required when the engine is warm. This is generally accomplished by closing a butterfly valve, known as the choke, fitted at the air inlet to the carburettor. With the choke closed only a small passage is left for access of air to the induction pipe. By turning the engine with the choke closed a partial vacuum is produced in the induction pipe and carburettor, and a large quantity of petrol is drawn from the jets. The choke should be used as sparingly as possible, as the excess petrol, flowing down the walls of the cylinders, washes away the lubricating oil and also dilutes the lubricating oil in the crank case.

Ignition system.—In gas and carburettor engines the mixture is ignited at the end of the compression stroke, by causing a spark to pass between the points of a sparking plug screwed into the

cylinder head. One point of the plug is connected to earth through the body of the plug and the engine cylinder, and the other point to the high-tension circuit through a distributor. Ignition systems are designed to produce a spark of the required intensity with the points of the plugs between fifteen and twenty thousandths of an inch apart. If the gap between the points is too small the spark will be weak, while if the gap is too large the spark will not pass. The high voltage necessary to cause a spark to pass across the gap between the points of a plug is obtained either from an induction coil or from a magneto.

An induction coil consists of a soft iron core on which is wound two coils of copper wire, known as the primary and secondary windings. In the primary winding there are relatively few turns, while the secondary winding consists of many thousands of turns of fine wire. By passing a current from a 6 or 12 volt battery through the primary winding, and suddenly interrupting this current, a very high voltage is induced across the terminals of the secondary winding.

In a magneto the primary current is generated by revolving the soft iron core, on which the two coils are wound, between the poles of a magnet, and a battery is not required. The magneto is driven from the half-speed shaft of the engine, and it does not give a good spark for starting unless the engine can be turned fairly rapidly. Large engines, with magneto ignition, are fitted with an impulse starter, which increases the speed of the magneto at the moment that the primary circuit is broken.

The interruption of the primary current is made by a cam-operated switch, known as the circuit breaker, which is driven from the half-speed shaft. For a four-cylinder four-stroke engine the primary current must be interrupted four times for each revolution of the half-speed shaft, *i.e.*, for two revolutions of the engine. At each interruption of the primary current, the secondary winding is connected to the sparking plug of one of the cylinders through the distributor. The distributor consists of a revolving arm, the end of which passes over contacts arranged in a circular path, one contact for each cylinder. The high-tension current passes to the distributor arm through a carbon brush, and each contact is led to a sparking plug through a length of heavily insulated flexible cable. Care must be taken, if the sparking-plug leads are disconnected, that they are reassembled correctly.

The time of opening of the circuit breaker must be so adjusted that a spark passes at each plug at the correct time. There is a short interval between the time that the spark passes and the time that the pressure rises due to the combustion of the fuel. To obtain the best results, the pressure in the cylinder should

reach its maximum as the piston commences its working stroke. To obtain this, when an engine is running at high speed, the ignition must be advanced, so that the spark passes when the crank is 20 or 30 degrees from the top dead centre. When starting an engine, the ignition should be retarded, so that the spark does not pass until the crank is on the top dead centre. By revolving the body of the circuit breaker, the spark can be adjusted to take place at any position of the piston, between top dead centre when fully retarded, and 30 degrees before top dead centre when fully advanced. Provision is made for this adjustment to be made by hand, and also in modern engines an automatic device is incorporated, which advances the spark automatically as the speed of the engine increases. If an attempt is made to start an engine without first retarding the spark, the rise in pressure in the cylinder will take place before the piston reaches the end of the compression stroke, and the engine may backfire, that is revolve a part of a revolution in the wrong direction. If an engine back-fires while being turned by hand, the operator may be injured as the starting handle will not disengage. If the ignition is advanced too far when an engine is running, a knock will be heard. Too-late ignition will cause a reduction in the power developed, and also the slow combustion produced by excessive retarding of the ignition will cause overheating of the exhaust valves.

A fault in the ignition system is the most common cause of break down. All the components must be kept dry, clean and in good order. The points of the circuit breaker will require attention; when fully separated the points should be about twenty-thousandths of an inch apart. As most carburettor engines are now fitted with a dynamo and battery for starting, it is the general practice to fit coil ignition. It is important that the battery be kept well charged, and that the ignition switch in the primary circuit should not be left made when the engine is stationary. If an engine fails to start, it can be ascertained if the fault is in the ignition system, by disconnecting the lead to a plug and holding the end close to an unpainted portion of the cylinder block, while the engine is turned. If a good spark is obtained, and if the plugs are clean and in good order, the fault is probably in the carburettor. An alternative method of testing the ignition system is by turning the engine with the plugs removed and laid horizontally on the top of the cylinders and the leads connected. It is possible, however, that while a spark may be obtained at each plug under these conditions, the plugs may not spark when the points are in air compressed to 150 lb. per square inch.

To prevent interference with wireless reception in the vicinity the high-tension leads and the sparking plug are now generally covered with a metallic covering which is conneoted to earth.

217. Fast-Type Motor Boats.—The petrol engines fitted in these boats are generally standard motor-car engines, modified as necessary for fitting in a boat. The smaller boats have one engine, while in the larger boats either two or three engines are fitted, each engine driving a separate propeller shaft. A hinged stop is fitted on the throttle lever of each engine, to limit the revolutions to that at which the engine will give satisfactory continuous running. This stop is only to be lifted in the case of an emergency, such as for the saving of life, and the engineer officer of the day is to be informed at the first opportunity if this has occurred.

As the engines can only run in one direction, a reversing gear is fitted between each engine and its propeller shaft. With the reversing gear in the neutral position, an engine can be run without the propeller shaft revolving. Each engine is fitted with a battery, a dynamo, and an electric motor for starting. The engines can be started and controlled, and the reversing gear operated, by the coxswain from the steering position.

The duty of the stoker of the boat is to maintain the engines in an efficient condition with regard to lubricating oil, water service, ignition system, batteries, etc. He should advise the coxswain to stop an engine should the lubricating oil pressure or water service fail, the clutch of the reversing gear slip, or other defects arise which would lead to serious damage if the engines were not stopped. He should also see to the lubrication of the remote control gearing, steering gear, and stern glands, and that the self-bailer is in good working order. The small hole on the top of the self-bailer suction pipe, which prevents water siphoning into the boat when not under way, must be kept clear. Should the boat be so heavily loaded that the top of the suction pipe is below the level of the water in which the boat is floating, the cock on this pipe must be closed.

As coil ignition is usually fitted to the engines of these boats, it is essential, if trouble in starting is to be avoided, that the batteries be kept well charged. By turning the engines a few revolutions by hand before starting from cold, the battery charge can be conserved.

The stoker of a boat should be acquainted with the position of the fire extinguishers provided, with the method of using them, and with the precautions to be taken to guard against an outbreak of fire, *see* articles 91-94, 110, 114-119. In boats where a methyl-bromide fire-extinguishing equipment is fitted, this should not be used for extinguishing small fires; which can be smothered with a damp cloth or put out with a small Pyrene extinguisher.

The handbook supplied by the makers should be consulted for instructions for starting and running of the engines.

218. Compression Ignition Engines.—The compression ignition engines which have been fitted in H.M. ships up to the present for driving electric generators and propelling ship's boats all work on the four-stroke cycle, and all except the Brotherhood Ricardo sleeve valve engine are fitted with poppet valves. Unlike the carburettor engines, compression ignition engines take into the cylinder each stroke a full charge of air, the speed of the engine and the power developed being controlled by varying only the quantity of fuel used.

To ensure complete and rapid combustion of the fuel it must be injected into the cylinder in the form of a fine spray, and the injection must be timed so that the combustion of the fuel will commence as the piston reaches the top dead centre, and be completed during the early part of the working stroke. Diesel obtained a fine spray by using compressed air at a pressure of about 900 lb. per square inch to force the oil through small holes in a number of steel discs, which are spaced a small distance apart with the holes staggered, so that the oil passing through the holes in one disc impinges on the plain part of the next disc. A constant stroke fuel pump is fitted for each cylinder. On the discharge side of each pump is a spill valve, which opens when the correct quantity of fuel has been discharged, and allows the remainder of the oil in the pump barrel to return to the suction side of the pump. Means are provided for varying the period of opening of the spill valve, and in this way the power output of the engine is controlled. The timing of the injection period is controlled by a cam-operated fuel valve on each cylinder, these valves being commonly known as the diesel valves. There are a number of these blast injection engines still in service, but all the latest compression ignition engines have what is known as solid or airless injection.

With airless injection the fuel is supplied to a fuel valve on each cylinder at a pressure of some thousands of pounds per square inch, and on the opening of this valve the fuel is forced through one or more small holes into the cylinder, the high pressure causing the fuel to be broken up into a fine spray. The first successful high-compression engine to employ airless injection was the submarine engine produced by Vickers in 1910. In this engine cam-operated fuel valves were fitted as in Diesel's engine.

The early oil engines ran at speeds not exceeding about 300 r.p.m. They were used in place of the steam engine for ship propulsion and driving electric generators. Small high-speed compression engines running at speeds up to 3,000 revs. per minute have recently been developed, and these engines are gradually replacing the petrol engine for the larger vehicles and boats, and they are also used for small electric generators. In the place of the cam-operated fuel valve these engines have, incorporated in each fuel sprayer,

an automatic spring-loaded fuel valve which opens when the discharge pressure of the pump is sufficient to overcome the compression of the spring. There is a separate fuel pump for each sprayer, and each pump has to provide the pressure necessary to lift the fuel valve at the correct time, to maintain this pressure during the injection period, and to allow the fuel valve to close quickly when the correct quantity of fuel has been injected. The manufacture of fuel pumps for these small high-speed engines is undertaken only by firms who specialise in this work. The pumps have to be capable of measuring out very small quantities of fuel with great accuracy and discharging against a high pressure. The pump most commonly fitted is the C.A.V.-Bosch pump described in the next article.

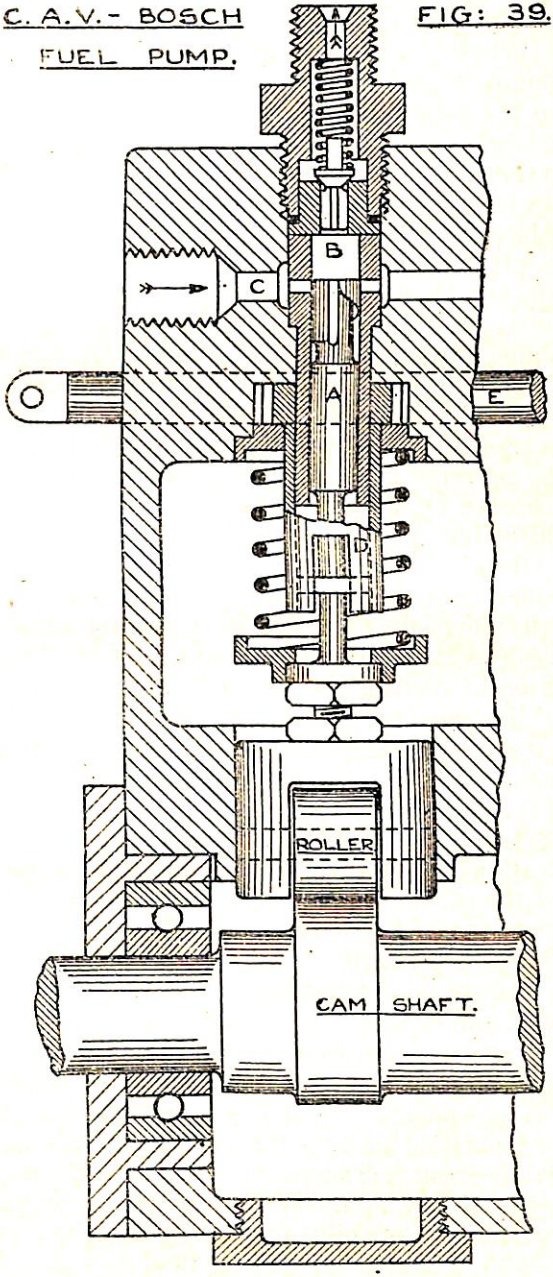
The type of sprayer fitted depends on the shape of the combustion chamber, and the extent to which turbulence or swirl of the air in the cylinder is employed to bring the fuel into contact with the oxygen necessary for its combustion. There are many different makers of airless injection engines, each with its own particular shape of combustion chamber and arrangement of fuel spray. In some, combustion takes place entirely in the space between the dished crown of the piston and the cylinder head, sprayers with a number of very small holes being fitted, and a high injection pressure used to distribute the fuel as uniformly as possible. Other makers provide a chamber in the cylinder head in communication with the space above the piston, and inject the fuel into this chamber. A sprayer with a single orifice is fitted to this latter type, and intimate mixing of the fuel and air is brought about, partly by the turbulence set up by forcing the air into the chamber during the compression stroke, and partly by the discharge of the fuel and air from the chamber into the cylinder during combustion.

It is of the utmost importance that the fuel used for compression ignition engines shall be free from particles of solid matter, which would choke the sprayers and cause wear in the fuel valves and fuel pumps. For the larger engines centrifugal separators are generally provided, and the fuel used is thoroughly cleaned in one of these separators before admitting it to the ready use tank. Where a separator is not provided gravity must be relied upon to cause any dirt or water in the fuel to settle out. The supply to the fuel pumps is taken from a point a few inches above the bottom of the tank, and a cock is fitted at the bottom of the tank through which dirty oil and water must be drained off periodically.

219. C.A.V.-Bosch Fuel Pump.—For small engines all the fuel pumps are incorporated in a common housing, in the bottom of which is fitted a cam shaft driven off the engine. Fig. 39 shows

C. A. V. - BOSCH FUEL PUMP.

FIG: 39.



a section through the pump for one cylinder. The pump plunger A is a very accurate fit in the barrel B. Rotation of the cam shaft raises the plunger, and a spring is fitted to ensure the return of the plunger when the cam has passed over the top dead centre. Above the pump barrel is a spring-loaded discharge valve, and there are two holes in the pump barrel communicating with the oil supply to the pumps through the passage C. When on the down stroke, the plunger uncovers the two holes in the barrel the pump will fill with oil. On the up stroke, when the plunger reaches the position shown in the sketch, the oil above the plunger will be compressed and the discharge valve will lift. The discharge valve will remain open and discharge to the sprayer continue until the right-hand hole in the pump barrel registers with a helical groove cut in the plunger, the remainder of the fuel in the pump being then free to return to the suction side of the pump, the discharge valve will close. The point in the up stroke of the pump at which the discharge pressure is released can be varied by rotating the plunger in the barrel. Two projections on the plunger rod engage with slots in sleeve D, which has at the top end a toothed wheel meshing with teeth on the control rod E. The control rod engages with a similar toothed wheel on each pump, so that when this rod is moved in one direction the output of all the pumps is increased, and when it is moved in the opposite direction the output of all the pumps is decreased. When the control rod is moved to the "stop" position, a vertical slot on each pump plunger comes into line with the hole on the right-hand side of each barrel, and no fuel is discharged. The control rod is operated by hand in the case of the engines fitted in boats, and by a constant speed governor in the case of the engines of electric generators. A bath of lubricating oil should be maintained in the lower part of the housing, to provide lubrication for the cams, rollers and guides. A dip stick is fitted to show the correct oil level.

220. Lubrication of I.C. Engines.—All I.C. engines are fitted with forced lubrication (*see* article 155). The smaller engines generally have what is known as a wet sump, which means that the bottom of the crank chamber forms a reservoir for the lubricating oil. The larger engines usually have a separate lubricating oil tank and two lubricating oil pumps driven off the engine, one pump pumping oil from the bottom of the crank chamber to the tank and the other from the tank to the bearings; this is known as a dry sump arrangement. Except in small boats' engines, an oil cooler is fitted in the system. When starting an engine will have run a few revolutions before oil from the engine-driven pump reaches the bearings, and if the bearings are dry they are likely to be damaged. A hand pump is therefore generally fitted so that oil can be pumped to the bearings just before starting the engine.

Admiralty I.C.E. lubricating oil is used for all I.C. engines, except those of the sleeve-valve type and certain high-speed boats' engines for which special oils are to be used. The escape of traces of the products of combustion, and under certain conditions unburnt fuel, past the piston rings of an I.C. engine, causes a gradual contamination of the lubricating oil. The oil in the lubrication system should therefore be changed periodically, more particularly in the case of petrol engines which are frequently stopped and started, as in these engines contamination of the lubricating oil with fuel is much more rapid (*see* article 216). Strainers are fitted in the suction side of the lubricating oil pump and filters on the discharge side, and this will interrupt all except the finest particles of carbon which pass into the crank chamber from the cylinders. These strainers and filters should be cleaned at frequent intervals and the filtering material renewed as necessary.

221. Cooling-Water Systems of I.C. Engines.—The necessity for a supply of cooling water for the cylinder jackets and cylinder heads of I.C. engines has been pointed out in article 211. The sea provides a convenient source of supply for marine engines, and until recently salt water was always used, a small pump driven off the engine being fitted to provide a supply of sea water to the engine. The disadvantage of using sea water is that this leads to the formation of scale on the surfaces being cooled, and this scale if allowed to become thick will prevent adequate cooling of the cylinders. The rate of formation of scale with sea-water cooling increases rapidly if the temperature of the water is allowed to exceed 130° F. In the engines of electric generators fitted with sea-water cooling there is generally a stand-by connection to the cooling system from the fire-main.

The modern practice is to use distilled water in the cooling system, and to circulate this water in a closed circuit from the engine through a cooler and back to the engine. One pump is fitted to circulate the fresh water, and another pump to supply sea water to the fresh-water cooler, this latter pump also supplying the oil cooler. A by-pass valve is fitted on the water cooler, so that the quantity of sea water passing through the cooler can be regulated, and thus the temperature of the circulating water controlled. With fresh water cooling a higher cooling water temperature should be maintained; the recommendation of the makers of the engine as to the best temperature should be followed. Shore water should not be used in the system as this may lead to the formation of scale.

When I.C. engines are not in use in cold weather all the water should be drained from the cooling system, if there is any possibility of its freezing. Should the water in any part of the system

be allowed to freeze damage to the engine will probably result, due to the increase in volume that takes place when water changes into ice.

222. Starting Compression-Ignition Engines. — Compression-ignition engines rely on the heat of compression to ignite the fuel when running. When starting from cold the temperature of the air at the end of the compression stroke will be lower than when the engine is warm. With some engines it is necessary to use glowing chemical cartridges or electric heater plugs to ensure ignition of the fuel when starting. The chemical cartridges, sometimes called fuses, consist of a roll of paper saturated with a chemical which causes the cartridge when ignited to smoulder for some minutes. One of these cartridges is fitted into a hollow plug provided on each cylinder, and just before turning the engine to start it, the cartridges are ignited and the plugs screwed into the cylinders. Some engines are fitted. with electric heater plugs. These plugs contain a coil of wire which becomes red-hot when current from a battery is passed through it. Switching on current to the plugs should be the last operation when preparing to start and the current should be switched off as soon as the engine fires. A press-button switch is generally fitted, and with this arrangement the circuit is broken when the operator releases the button.

A variety of means are adopted for turning compression-ignition engines for starting. Very small engines may have hand starting, but due to the high compression pressure special provision must be made to make turning by hand easier. Where hand starting is used either decompression or half-compression gear is fitted. This gear, by holding open the inlet valve during part or the whole of the compression stroke, makes it easier to turn the engine. In engines with half-compression gear and fitted with heater plugs, the engine will fire under half-compression. With decompression gear the engine is revolved as fast as possible by hand with no compression, so that sufficient energy is stored in the flywheel to assist in turning the engine, when it is suddenly thrown over to full compression.

Larger engines are fitted, either with an electric or air motor for starting, or an arrangement is provided whereby the engine may be turned by admitting compressed air to the cylinders. With electric or air motor starting the motor drives a pinion which meshes with teeth on the fly wheel, and this pinion is thrown out of gear automatically when the engine fires.

In engines with direct compressed air starting the supply of air to the cylinders is controlled, either by a cam operated air starting valve on each cylinder, or by a rotary valve driven from the cam shaft, which admits air in turn to each cylinder, through a spring-

loaded non-return valve, as the piston in that cylinder commences the working stroke. With cam-operated air starting valves, it is arranged that these valves only come into operation when the starting air is turned on. It is not essential that the engines of electric generators should start instantly from any position, and some of these engines have direct air starting to only a portion of the cylinders; before turning on the starting air, such an engine must be turned by hand to a position where an air starting valve on one cylinder is open, these positions will be found marked on the fly wheel.

When air starting is fitted, one or more air bottles are provided in which a sufficient quantity of compressed air can be stored to give at least six starts of the engine without replenishment. The air bottles are charged, either by a compressor driven from the engine, or by an independent compressor driven by a small single cylinder I.C. engine which can be started by hand. With the former arrangement the compressor can be declutched when the air bottles are fully charged. The compressor should always be clutched in before starting the engine, as the clutch cannot be engaged with the engine running. Care must be taken that the air compressor and bottles are kept drained, *see* Article 210.

Even those engines which cannot be started by hand are provided with hand-turning gear, by means of which the engine can be turned slowly. Before attempting to start an engine, it should be turned two complete revolutions by hand, to ascertain that the engine is free, and that no water has leaked into any of the cylinders from the jackets. It should also be ascertained before attempting to start an engine that the fuel system is fully charged. In some engines, each fuel pump can be worked by hand after turning the engine so that the roller is on the lowest part of the cam. If the fuel system has been dismantled, it will be necessary to slack back the union on the fuel supply pipe at the sprayers until all air in the system has been discharged. The lubricating oil and cooling water systems should be examined before starting, and oil pumped to the bearings. If on starting a pressure does not show immediately on the gauge on the forced lubrication system, the engine should be stopped at once. A handbook which gives detailed instructions for starting, running and maintenance is provided with each engine.

CHAPTER XVI.

MATERIALS.

223. Properties of Metals.—In the design of boilers and machinery certain properties of the metals used must be taken into consideration. The properties of general interest are the ability of the metal to withstand tensile and compressive stresses, ductility, resistance to corrosion, scaling and loss of strength at high temperatures.

The tensile strength is measured by subjecting a small round rod of the metal to an increasing tensile load until the test piece fractures. The maximum load per square inch of cross sectional area that the test piece withstands is called the tensile strength of the metal.

Ductility is the property that allows a material to be permanently deformed to a substantial amount without fracture, and under stress a ductile material is more liable to deform than fracture.

When a test piece of a ductile material is broken under a tensile load an appreciable amount of permanent stretch, together with a reduction in cross sectional area, takes place in the vicinity of the fracture. The amount of permanent stretch or elongation, expressed as a percentage of the original length of the test piece, is commonly used as a measure of the ductility.

224. Ferrous Metals.—For convenience, metals and their alloys may be divided into two groups :—

(1) Ferrous Metals—those chiefly composed of iron.
(2) Non-ferrous Metals—those with little or no iron.

The ferrous metals of importance in marine engineering are :—

(*a*) cast iron,
(*b*) wrought iron,
(*c*) steel,
(*d*) alloy steels.

(*a*) *Cast Iron.*—Iron ore, treated in a blast furnace, yields a molten metal containing only a small proportion of the impurities of the ore. When the molten metal is cast into roughly-shaped bars, it is known as pig iron. Pig iron remelted and cast to shape is called cast iron. A very strong cast iron may be made by melting pig iron with a proportion of steel.

In addition to iron, cast iron contains about 3 per cent. carbon, 2 per cent. silicon, and smaller amounts of manganese, phosphorus and sulphur. By controlling the amounts of these, different varieties of cast irons, having properties suitable for many kinds of purposes, may be produced. Nickel, chromium, copper and molybdenum are metals that are sometimes added to produce irons with

special properties, *e.g.*, non-magnetic, corrosion-resistant, heat-resistant.

Cast iron is widely used for making castings of intricate form, such as slide valves, because it accurately takes the form of a mould, is easily melted in large quantity and is the cheapest of all metals used in engineering.

Although it is a brittle metal, and therefore unable to resist the shock of a sudden blow, cast iron is one of the strongest materials for withstanding compression, and is therefore used for pillars in structures ashore and also for parts of ships' machinery where resistance to shock is not required.

The shape of a piece of cast iron cannot be permanently changed, without fracture, by hammering, squeezing or by drawing, so that it is said to lack malleability and ductility. The common varieties of cast iron readily lend themselves to all kinds of machining operations such as sawing, turning, boring and grinding.

Compared with castings of steel, iron castings are weaker in tension but are more easily produced and the foundry work is less expensive.

The tensile strength of cast iron is usually as follows :—

Ordinary cast iron .. .. 10-17 tons per square inch.
High-strength cast iron .. .. 17-30 tons per square inch.

Parts of ships' machinery commonly made of cast iron are :—auxiliary steam-engine cylinders, pistons, motor boat cylinders and pistons, piston rings, laps and cylinder liners, turbine gear cases and crank cases. Cast iron is not allowed for steam pipe and boiler fittings, nor for parts in contact with superheated steam, because the metal deteriorates by long exposure to high temperatures.

(*b*) *Wrought Iron.*—The production of pig iron from iron ore in the blast furnace may be regarded as the first stage of a process to obtain a metal that possesses the ability to be worked either hot or cold. Long before the invention of a cheap and rapid method of making steel from pig iron, a ductile metal called wrought iron was made from pig iron.

Wrought iron was, and still is, made from certain kinds of pig irons by melting them in a suitable furnace and oxidising or burning the impurities. The gradual oxidation of the impurities results in the formation of almost pure iron in a pasty condition, entangled in slag which is produced from the oxidised impurities. The pure iron formed is not molten because its melting point is much higher than that of the pig iron and the temperature of the furnace is too low. Upon removal from the furnace, the iron is squeezed while hot, in order to get rid of as much slag as possible but a little always remains ; the squeezing of the iron in the presence of slag gives the metal a fibrous structure which is the essential characteristic of good-quality wrought iron.

Wrought iron is always worked to shape, and this may be done either hot or cold ; it is easily forge-welded and machined. Wrought iron stands repeated heating and forging without deterioration and is very resistant to atmospheric corrosion.

Steel and wrought iron are equally well suited for many purposes, but steel is practically always used because it is cheaper.

Since wrought iron melts at a high temperature, it is used for fire-bars in coal-fired furnaces. Nuts of wrought iron were formerly used on steel bolts exposed to heat, because they do not seize on the threads.

The tensile strength of wrought iron is usually between 22 to 24 tons per square inch.

(*c*) *Steel.*—Formerly steel was made only from wrought iron by adding carbon, and could only be made in small quantities at a time, and was therefore expensive. The inventions of Bessemer, and later those of Gilchrist, Thomas, Siemens, Martin and others, made possible the cheap production of steel from pig iron or from pig iron mixed with steel scrap. These are melted in the presence of oxidising materials, so that the carbon and certain impurities are gradually burned away. Generally it is not possible to reduce the amount of impurities to the required extent without burning away practically all the carbon ; in consequence, sufficient carbon must be put back into the metal to produce the type of steel required. Small amounts of metals, such as manganese, may also be added to free the molten steel from the iron oxide and gases. When ready, the molten steel is either cast to shape or cast into ingots for subsequent forging.

The physical properties of a steel chiefly depend upon the amount of its carbon content. One reason why such a small quantity of carbon exerts so powerful an effect is that its weight is magnified 15 times by combination with part of the iron to form iron carbide. Thus, a steel with 0·5 per cent. carbon actually contains 7·5 per cent. iron carbide. As the carbon content of steel is increased the tensile strength increases, but the ductility and resistance to shock diminish. Table I shows the percentages of carbon and the tensile strengths of steels used in ship's boilers and machinery. Unlike cast iron, steel has about the same strength in compression as in tension.

The properties of any carbon steel may be changed by suitable heat treatments. Nearly all steel for marine use, with less than 0·4 per cent. carbon, is used in the annealed or in the normalised conditions ; in these states the steels possess the best combinations of strength, ductility, machinability and resistance to shock at the cheapest price. Generally, carbon steel with high tensile strength is not used for machine parts, because it is not sufficiently ductile. Hence it is usual to specify the highest and lowest tensile strength a steel may have when used for a particular purpose.

TABLE I.—CARBON STEELS.

Type of Steel.	Boiler or Machinery Part.	Tensile Strength. Tons per sq. in.	Elongation. Per cent.	Carbon Content. Per cent.
Mild Steel, Rolled or Drawn.	Boiler	21—26	27—23	From ·15 to ·25
	Steam pipes	24—27	25	
	Rivets	26—30	25	
	Boiler drum end plates, doors, etc.	26—30	23	
	Bars for nuts	28—32	29	
	Boiler drums—rolled and rivetted.	28—32	20	
	Bars for bolts	30—35	23	·2 to ·3
Forged Steel.	Boiler steam drums and superheater headers forged	28—32	29	From ·15 to ·25
	Crankshafts, turbine rotor dummies, small reciprocating engine pistons	28—32	29	
	Ordinary forgings, *e.g.*, turbine rotor drums and gear wheel rims	31—35	26	
	Turbine Rotor Wheels and shafts, gear wheel and thrust shafts. Propeller shafting	34—38	23	
	H.P. Air Bottles	40	18	·4—·48
	Carbon steel for tools	—	—	·6—1·25
	Springs	95—120	—	·7—·8
Cast Steel.	Ordinary castings	29—34	20	Generally does not exceed ·3
	Intricate castings	31—36	18	
	Pistons	34—38	17	

For boiler drum ends and tubes, and for steam pipes, ductile material is chosen for ease of fabrication and on account of the strains set up due to expansion when heated.

The high carbon steels are used for tools and springs because they develop great hardness after heating to a suitable temperature, quenching and tempering. Tool steel must be hard but not too brittle, and springs are required to be hard and resilient.

The surface of mild steel may be made very hard and resistant to wear, by a case-hardening process. This consists of heating the surface to be hardened in contact with carbon at about 900° C., whereby the surface of the metal absorbs carbon. After this, the steel is heat-treated so that the carburised surface is made very

hard but the greater part of the metal below the surface retains the ductility and toughness of mild steel. Steel parts exposed to wear are usually case-hardened, *e.g.*, gudgeon pins of internal combustion engines. It must be remembered that the strength properties of machinery parts may have been obtained by special heat-treatments. Subsequent heating may destroy the effects of these, and it is therefore important that no machinery parts (including nuts and bolts) should be subsequently heated without the permission of the Engineer Officer in charge.

(*d*) *Alloy Steels.*—When metals such as manganese, chromium, nickel, molybdenum, tungsten, vanadium and copper, are alloyed with steel in suitable amounts, the resulting alloys are known as alloy steels. The object of adding different metals to steel is to enhance some particular property of the steel, such as tensile strength or resistance to corrosion. The amount of alloying metal added depends on a large number of factors, too numerous to discuss in this short description. Alloy steels are more expensive than carbon steels, and therefore are only used where their special properties can be used to advantage. To develop these properties, special heat-treatments suitable for the steel in question are generally required. Unless these are carried out, the steel is not in the best condition for service, and efficient use is not made of it.

In marine engineering alloy steels are not extensively used, because for the weight allowed most requirements can be more cheaply and more efficiently met by the use of carbon steels.

The principal alloy steels used in ships' boilers and machinery may be classified as follows :—

Group 1.—Nickel and nickel-chrome steels used for highly stressed parts requiring high strength, ductility and resistance to shock, *e.g.*, gearing pinions, connecting rod bolts, highly stressed crankshafts.

Examples :—Nickel-steel forgings for gearing pinions. Carbon 0·3 per cent, nickel 3·5 per cent. Tensile strength 40 tons per sq. inch, elongation 23 per cent.

Group 2.—Stainless iron and stainless steels, used where resistance to corrosion is required, or where erosion by steam must be withstood, *e.g.*, turbine blading, valves and spindles.

Example :—(i) Chrome steel forgings for valves and spindles. Carbon 0·3 per cent., chromium 13 per cent. Tensile strength 45–50 tons per sq. inch, elongation 25 per cent. (ii) Stainless steel turbine blading. Carbon less than 0·12 per cent., chromium 12·5 to 14·5 per cent. Tensile strength 30–40 tons per sq. inch, elongation 25 per cent.

Group 3.—Heat-resisting steels used where strength and

resistance to scaling at high temperatures are required, *e.g.*, superheater tube supports.

Example :—Heat-resisting steel castings and forgings for superheater tube supports. Carbon 0·35 per cent., chromium 21 per cent., nickel 7 per cent., silicon 1·5 per cent., tungsten 4 per cent. Possesses strength and well retains its dimensions under load at high temperatures.

225. Non-Ferrous Metals.—Certain non-ferrous metals, such as copper and lead, are used in their pure state as well as in the form of alloys. Pure metals are usually employed in the form of sheets, tubes and wire, or as thin coatings on other metals. Precious metals, such as platinum and silver, are used in very small quantities and chiefly in electrical instruments.

Copper, aluminium, lead and zinc are the pure metals used in largest quantity and, as a matter of interest, the world production of some of the metals for the year 1937 is given in the following table.

Metal.	Tons.
Copper	2,306,000
Lead	1,659,000
Zinc	1,593,000
Aluminium	474,000
Tin	199,000
Nickel	113,000
Silver	8,472
Gold	1,025
Pig iron	102,112,000

The tonnage of the above metals are approximate and only represent new metal, *i.e.*, metals extracted from ore. (The ton unit used in the table is that of 2,240 lb. avoirdupois.)

Nickel, chromium, cadmium and zinc are used in the form of electro-plated deposits on other metals. Tin and zinc coatings on steel sheets are made by dipping the sheets in molten metal. Zinc and many other metals can be sprayed to form protective coatings. Mercury, the only metal liquid at room temperature, is used in thermometers and certain types of barometers and pressure gauges.

Copper.—This is the only pure metal with a red colour ; except for gold, which is yellow, all other pure metals are some shade of silvery grey or silvery white tinged slightly with blue or yellow.

Copper is soft and very ductile and may be cold worked to a high degree, so that bars, tubes, wire and sheets are easily produced.

With the exception of silver, copper is the best metallic conductor of electricity (and heat), and is therefore extensively used for electrical purposes.

Though copper is too weak a metal for use in moving parts of machinery, it is used in ships for many kinds of pipes, especially those coming into contact with sea water.

Copper is hardened by cold work, such as hammering or vibration, and to restore its ductility the metal must be annealed at about 400° C. Copper pipes, subjected to vibration, must be periodically annealed, to prevent their rupturing due to becoming too hard. Annealing copper in a reducing flame embrittles the metal and therefore an oxidising flame should be used.

Copper is difficult to cast free from blowholes and when castings are required the copper may be alloyed with a small percentage of chromium.

The tensile strength of copper is as follows :—

Annealed	..	14·9 tons per square inch, elongation 30 per cent.
Cold worked	..	30 to 32 tons per square inch, elongation 5 per cent.

Copper may be brazed or soldered but the ordinary commercial copper cannot be welded satisfactorily.

Lead.—This metal has a silvery grey appearance, slightly tinged with blue. It is very malleable and ductile, but heavy and weak, and so soft that, rubbed on paper, it leaves a black streak.

In engineering, lead is used in the form of alloy for the sheathing of electric cables, accumulator plates, solders and bearing metals. Large quantities of lead are converted into paints, ammunition, printing type, foil and sheet.

Lead is used for hammers and for covering the jaws of vices, when it is desired not to injure the article which is to be hit or gripped.

Zinc.—This is a fairly hard metal, silvery blue-white in colour, easily cast and able to be rolled into plates and bars. One of its chief uses is for "galvanising" iron and steel articles; in this process the articles are dipped in molten zinc whereby they receive a thin coating of the metal which protects them from corrosion for a considerable time.

Zinc plates or bars are sometimes placed in boilers and distilling plants and other parts to protect the surfaces of these from corrosion; this is made possible by the fact that when zinc is in electrical contact with these the zinc is more readily attacked and dissolved than steel or gunmetal. In consequence of this, the zinc protection pieces must be renewed from time to time.

Large quantities of zinc are required for alloying with copper to make brass and for making alloys suitable for cheap die-castings.

Aluminium.—This metal can be worked and fabricated by the usual metal-working processes such as rolling, stamping, spinning, drawing and the like, but it is difficult to cast because of the large

shrinkage on solidification, and therefore castings of pure aluminium are not made. Except for magnesium and beryllium, aluminium is the lightest of the structurally useful metals.

Aluminium has good electrical conductivity, and reinforced with steel it is used for overhead electrical land cables. It is a good conductor of heat, and in its alloys this property is made use of in pistons and cylinder heads for internal combustion engines.

Aluminium forms, in contact with moisture, a thin film of oxide, which protects it against further attack. It can be electrolytically oxidised, *i.e.*, anodised to give a thicker oxide film of great hardness and resistance to corrosion, and many alloys of aluminium can be similarly treated. Aluminium and most of its alloys are readily corroded by sea water, unless specially coated by protective films.

Pure aluminium has low-tensile strength and has poor machining properties, so that it finds its chief applications in the form of sheets, wire and bars. Aluminium paint is made from the powdered metal and forms a durable and protective coating for both metal and wood against some forms of corrosion attack.

Tin.—This is silvery white in colour, malleable and sufficiently soft to mark paper. It is a rather costly metal. Thin sheets of steel dipped in molten tin become coated with a thin layer of the metal, and are known as " tin-plate " ; the tin protects the steel from corrosion, because tin is not readily attacked. Brass condenser tubes in distilling plants are coated with tin in order to avoid contamination of distilled water, used for drinking, by dissolved copper salts.

Tin is required for the preparation of the alloys bronze, gunmetal, naval brass, white metals and solders.

226. Non-Ferrous Alloys.—There is no generally accepted system of naming the non-ferrous alloys and these may be called by historic names, trade names and by names of inventors. Another method of describing alloys is by their composition. A guide to the names of alloys will be given under the different alloy groups.

The Brasses.—The word " brass " is commonly used as a general term for the copper-zinc alloys, although it is sometimes confined to the copper-zinc alloys containing 55 per cent. to 80 per cent. copper.

The various brasses are, in general, characterised by the ease with which they can be cast, extruded, forged, rolled, pressed, drawn, machined or otherwise fabricated, and because of this they are probably the most important non-ferrous alloys. The brasses also show marked resistance to atmospheric and marine corrosion, and are therefore used in the manufacture of machinery, equipment and instruments exposed to adverse conditions.

There are two main groups of brasses, viz. :—

(1) those containing more than about 63 per cent. copper ; this group is specially suited for cold working, as for example, cold rolling into sheets, wire drawing, cold pressing, and tube drawing. Alloys in this group are generally more resistant to corrosion by sea water, especially when they contain a small quantity of aluminium or tin.

(2) those containing less than about 63 per cent. copper, but more than 55 per cent. ; this group is specially suited for casting, hot working by rolling, extruding and hot stamping. Alloys in this group are generally stronger, but less ductile than Group (1).

In addition to all these, other brasses are made by adding small amounts of other metals, such as tin and aluminium, in order to enhance some particular property, *e.g.*, resistance to corrosion, tensile strength.

Typical alloys of the above two groups are set out in Table II, a study of which will show that the use of any particular alloy depends on some special property, *e.g.*, ability to be worked hot or cold, resistance to corrosion, and so on.

Bronzes.—The true bronzes are the copper-tin alloys, but the term bronze is often wrongly applied to other alloys, for example, high tensile brass has long been called manganese bronze, and an alloy of copper with about 10 per cent. aluminium is known as aluminium bronze. True bronzes to which additions of other metals are made may rightly be referred to, for example, as phosphor-bronze, nickel-bronze, lead-bronze, zinc-bronze (gunmetal).

The bronzes may be classified into two groups :—

(1) bronzes with less than 6 per cent. tin ; these may be cold worked,

(2) bronzes with more than 6 per cent. tin ; these are used for castings.

Alloys in group (1) are generally made to contain small amounts of phosphorus and are used for turbine blading and valve spindles. These alloys are strong, ductile and resistant to corrosion.

Alloys in Group (2) include gunmetal, cast phosphor bronzes, bell metal and others.

Gunmetal derives its name from its former use for guns. Admiralty gunmetal contains approximately 88 per cent. copper, 10 per cent. tin, and 2 per cent. zinc, the zinc being added to facilitate casting. This metal is strong, ductile, resistant to shock and possesses great resistance to corrosion by sea water. Gunmetal is favoured for castings subject to pressure and like the majority of bronzes, it does not readily spark when struck. Castings in Admiralty Gunmetal may be used for steam up to temperatures of about 350° C. (662° F.).

TABLE II.—TYPES OF COPPER-ZINC ALLOYS.

Group.	Name of Alloy.	Typical Limits of Composition.				Minimum Tensile Strength. Tons/sq. in.	Minimum Elongation. % (on 4 in.).	Typical Uses of Alloy.
		Copper. %	Zinc. %	Lead. %	Other Metals and Impurities. %			
Group 1	Gilding metal and metal for flanges.	90	10	—	—	16 annealed ..	About 50	Decorative work and flanges for copper pipes.
	Cartridge brass ..	68—74	Rem.	·07 max.	Impurities—very low ..	19 annealed ..	About 55	Drawn articles, deep pressings, *e.g.*, cartridge cases requiring high ductility and strength.
	65/35	65 min.	Rem.	·35 max.	Total impurities, ·75 ..	Annealed 18 Half hard 22 Hard rolled 30	About 40 ,, 25 ,, 10	A ductile alloy for cold press work.
	Basic brass ..	62—64	Rem.	·3 max.	Total impurities, ·6 ..	Annealed 18 Half hard 25 Hard rolled 30	About 40 ,, 15 ,, 5	A typical alloy for general cold press work.
Group 1 modified by added metals.	Tin brass	70 min.	Rem.	—	Tin, 1·0 min. Total impurities, ·3 max.	—	—	Admiralty tubes for condensers, surface heaters, coolers, screwed ferrules and cone packing rings
	Aluminium brass ..	76—78	Rem.	·03 max.	Aluminium .. 1·8—2·3 Arsenic .. ·01—·05 Impurities .. ·3 max.	—	—	Admiralty tubes for condensers, surface heaters and coolers.
Group 2	Yellow metal or Muntz metal.	59 min.	Rem.	—	Total impurities, 1·0 max.	22	30	Brass sheets, plates and strip which do not experience much cold work during manufacture. The alloy works well when hot.
	Brass for hot stamping, free cutting castings, etc.	54—62	Rem.	2·0 max.	Total impurities, ·75 max. Lead is added to improve machinability.	20	25 (on 2 in.)	Brass bars and sections suitable for forging.
Group 2 modified by added metals.	Naval brass ..	61 min.	Rem.	—	Tin, 1·0 min. Impurities, ·75 max.	22—26	20 (on 2 in.)	Sheets, plates, bars, condenser tube plates, ferrules, diaphragms, small valves, spindles.
	High tensile brass ("Manganese bronze.")	54—62	Rem.	—	Manganese, aluminium, iron, nickel, tin, approx. total, 5 %	30—35	20—25 (on 2 in.)	High tensile alloys for casting, extrusion hot stamping. Propellers, H.P. air service, hydraulic service. Bolts and nuts.
Spelter for brazing	Special	70	30	—	—	—	—	Used for brazing stainless iron turbine blades.
	Grade A	64	46	—	—	—	—	For general brazing.
	Grade B	50	50	—	—	—	—	

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In the service, Admiralty gunmetal is used for a large variety of castings, *e.g.*, bearing shells, pump-bodies, valves and cocks, condenser doors, etc.

The average tensile strength of Admiralty gunmetal is 16·0 tons per square inch and the elongation about 14·0 per cent.

Aluminium Alloys.—In the service, out of the many aluminium alloys available, two main types are used for engineering purposes; these are (1) silicon aluminium; and (2) Y alloy, duralumin and R.R. alloys.

The silicon aluminium alloy contains about 13 per cent. silicon and is somewhat lighter than pure aluminium. The alloy is easily cast and is only used in the form of castings; it has considerable resistance to atmospheric corrosion, is easily machined and may be welded. The silicon aluminium alloy is used for handwheels, fuel line fittings, oil filter bodies, etc. The tensile strength of the alloy is about 11 tons per square inch, and the elongation about 5 per cent.

Y-alloy has the following approximate composition :—

	Per cent.
Copper	4
Nickel	2
Magnesium	1·5
Silicon	·5
Aluminium	remainder.

It differs from duralumin in containing nickel, but is similar in type to the R.R. alloys.

Y-alloy may be used for castings and may be forged, rolled and extruded. The strength of the alloy is improved by heat-treatment, which consists of heating it at 510 to 520° C. and quenching in cold water. In this state Y-alloy is soft, but after standing at room temperature, or after exposure for a short time at higher temperatures (100 to 250° C.) the metal hardens and strengthens.

Y-alloy is used for castings and forgings subject to stress or heat and is used for pistons of internal-combustion engines.

Copper Nickel Alloys.—Several of these alloys are of importance in marine engineering because of their outstanding resistance to corrosion, great strength and ability to be worked hot or cold. The alloys are all of one type and their properties are only affected by comparatively large changes of composition; experience has shown two alloys to be of most general application, and these are Monel and the so-called cupro-nickel.

Monel contains about 70 per cent. nickel and is directly produced from a nickel ore containing copper, whereas cupro-nickel is made by alloying the two metals in the proportion of 70 per cent. copper and 30 per cent. nickel.

Monel metal may be readily worked hot or cold, and with additions of small amounts of silicon may be used for castings.

Monel metal is used for small valves, spindles, steam strainers, pump rods, etc. Pump impellers are cast in silicon monel.

The principal use of 70/30 cupro-nickel is for condenser tube and ferrules.

White Metal.—Nearly all the bearings of marine engines and of important auxiliaries, in the Service, are fitted or lined with a soft white metal which generally consists of about 3 to 4 per cent. copper, 8 to 9 per cent. antimony, and the remainder tin. It is a soft and plastic metal, which when well lubricated will sustain great pressure without heating.

Stern tube and " A " bracket bearings of many smaller vessels are not fitted with lignum vitae strips, but are lined with a special white metal suitable for use in sea water. This consists of about 29·5 per cent., zinc, 1·5 per cent. copper, and the remainder tin.

Solder.—Metals capable of receiving a coating of tin may, when heat is applied, be united by means of solder. The solders are usually alloys of tin and lead, and there are two commonly used

Fine or tinman's solder .. 2 parts tin, 1 part lead.
Coarse or plumber's solder.. 1 part tin, 2 parts lead.

Tinman's solder solidifies very quickly after being applied, but plumber's solder takes longer to set and therefore provides time for a plumber to " wipe a joint."

The above two tin-lead solders melt in the temperature range 360° to 430° F. (183° to 221° C.) and have low strength ; they are therefore not suited for joints exposed to either stress or heat. Jointing alloys, stronger than these solders and melting at higher temperatures, are the brazing metals ; as the name implies, these are varieties of brasses and include

Silver solders—

Melting range, 1,200° to 1,600° F. (649° to 871° C.).

Brass and nickel " silver " brazing alloys—

Melting range, 1,600° to 1,700° F. (871° to 927° C.).

Two silver solders most commonly used have the following approximate compositions—

	Silver.	Copper.	Zinc.
Alloy A ..	61	29	10
Alloy B ..	43	37	20

Compositions of brazing brasses have been given in Table II.

The so-called nickel " silver " contains no silver, but is a brass containing nickel.

The use of any brazing metal is determined by such consideration as the melting range of the metal, strength, electrical conductivity, appearance and the properties of the metals to be joined.

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